

STA-11
2453
29

Box Core Number
NOAA CRUISE (MAY 1975)
VANE SHEAR DATA SHEET

MGG03045001

Date/Time of Collection
28 MAY 1346 (PDT)
29 MAY 1520 (PDT)

Test Location: Longitude 16°0.7'N
Latitude 126°46.30'W

Torque Indicator Serial Number 2249

Date/Time of Testing

Box Core Retrieval Depth: 4585 METERS

Vane Size 1"

Rate: 1 rpm (hand torque wrench)

Box Core 53

Depth of Penetration from top of sediment	VS-1				VS-2				VS-3			
	Undisturbed P _{max}		Remolded Residual		P _{max}		Residual		P _{max}		Residual	
	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI
5 cm	1-4	1595	0-6	1785	1	1476	0-4	119	1	1476	0-6	1785
10 cm	2	1520	0-12	1357	2-6	11305	1	1476	2-4	1071	0-14	14165
20 cm	2-6	11305	1	1476	2-6	11305	1-2	15355	2-2	10115	1	1476
30 cm	2	1152	1	1476	2-2	10115	1	1476	2-8	119	1-2	15355
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 40 CM DEEP
B						VERY UNIFORM COLOR
C						AND TEXTURE
D						SMALL NODULES
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing. (eliminates friction)

Comments:

Tested by:

(use back side for additional comments)

STA-14

NOAA CRUISE (MAY 1975)

Box Core
Number 7038

VANE SHEAR DATA SHEET

MGG03045001

Date/Time 22 MAY 7
of Collection 0525 (PDT)

Test Location: Longitude 15° 00' N
Latitude 126° 34' W

Torque Indicator
Serial Number 2249

Date/Time 22 MAY 7
of Testing 0650 (PDT)

Box Core
Retrieval Depth: 4526 METERS

Vane Size 1"

Box Core 38

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	0-14	.4165	0-4	1-6	.6545	0-6	1-8	.714	0-8
10 cm	1-12	.833	0-12	2-4	1.071	0-14	2-6	1.1305	1-4
20 cm	2-4	1.071	1-2	2-6	1.1305	1-4	3	1.428	1-8
30 cm	2-10	1.2495	1-4	2	.952	1	3	1.428	1-4
40 cm									
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE DEPTH 39 CM SMALL NODULES
B						UNIFORM THICKNESS
C						AND COLOR, COLOR
D						DARK BROWN
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

(use back side for additional comments)

508114

Box Core
Number

11-39

NOAA CRUISE (MAY 1975)
VANE SHEAR DATA SHEET

MGG03045001

Date/Time
of Collection

22 MAY 1984 (PDT)
0840

Test Location:

Longitude 15° 14' 50" N
Latitude 126° 30' 30" W

Torque Indicator
Serial Number

2249

Date/Time
of Testing

22 MAY 1984 (PDT)
1020

Box Core
Retrieval Depth:

4581 METERS

Vane Size

1"

Box Core 39

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	1	.476	0-6	.1785	1	.476	0-6	.1785	0-6
10 cm	2-4	1.071	1	.476	1-14	.8925	0-12	.357	2-8
20 cm	3-14	1.8345	1-12	.833	3-10	1.7155	1-14	.8925	3-6
30 cm	3-10	1.7155	1-6	.6545	3-12	1.775	1-12	.833	3-12
40 cm									
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 35cm DEEP
B						small nodules on top
C						medium brown color
D						
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by:

STA 14

Box Core
Number

12-40

NOAA CRUISE (MAY 1975)
VANE SHEAR DATA SHEET

MGG03045001

Date/Time 22/MAY (PDT)
of Collection 1146

Test Location: Longitude 15° 15' N
Latitude 126° 29' W

Torque Indicator
Serial Number 2249

Date/Time 22/MAY (PDT)
of Testing 1320

Box Core
Retrieval Depth: 4500 METERS

Vane Size 1"

Box CORE 40

Depth of Penetration from top of sediment	VS-1				VS-2				VS-3			
	P _{max}		Residual		P _{max}		Residual		P _{max}		Residual	
	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI
5 cm	1-12	1833	0-8	238	1-10	17735	0-14	4165	1-14	8925	0-12	1357
10 cm	2-8	119	1-2	5355	2-2	10115	1	1476	2-2	10115	0-14	14165
20 cm	2-10	12495	1-2	5355	2-2	10115	1-2	5355	2-4	1091	1	1476
30 cm	1-14	8925	0-14	4165	1-12	1833	0-14	4165	2-4	1091	1	1476
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 40CM DEEP ABOUT 1/2 33CM DEEP OTHER
B						VERY FEW SMALL
C						nodules
D						FEW LIGHT COLOR
E						VEINS IN COLOR

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

(use back side for additional comments)

Box Core
Number 41 43 STA-14

Date/Time 22 MAY
of Collection 1531 (PDT)

Date/Time 22 MAY
of Testing 1655 (PDT)

NOAA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

MGG03045001

Test Location: Longitude 15° 14' 20" N
Latitude 126° 29' 20" W

Torque Indicator
Serial Number 2249

Box Core
Retrieval Depth: 4559 METERS

Vane Size 1"

Box Core 41

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	1-2	15355	0-10	2	952	0-12	1-14	18925	0-10
10 cm	1-12	1833	0-14	2-14	13685	1-6	2	1952	1
20 cm	2-4	1091	1-2	2-8	119	1-2	2-6	11305	1-2
30 cm	2-8	119	1-8	2-10	12495	1-8	2-8	119	1-6
40 cm									
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A	~					CORE 37CM DEEP
B						VERY FEW nodules
C						Color medium Brown
D						
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

Box Core
Number 42-14 STA-14

NOAA CRUISE (MAY 1975)
VANE SHEAR DATA SHEET

MGG03045001

Date/Time 22 MAY
of Collection 1836 (PDT)

Test Location: Longitude 15° 15' N
Latitude 126° 29' W

Torque Indicator
Serial Number 2249

Date/Time 22 MAY
of Testing 2030 (PDT)

Box Core
Retrieval Depth: 46.36 METERS

Vane Size 1"

Box CORE 42

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
5 cm	1-2	.5355	0-8	1.238	0-12	.357	0-6	.1785	1-2	.5355	0-10	.2975
10 cm	5-2	2.4295	2-6	1.1305	5-4	2.489	2-8	1.19	5-8	2.608	3	1.428
20 cm	5-8	2.608	2-8	1.19	5-4	2.489	2-12	1.309	5-12	2.727	3-2	1.488
30 cm												
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 30cm DEEP
B						VERY STIFF MUD
C						FEW MEDIUM SIZE
D						nodules
E						Uniform coloring

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

Box Core
Number

2750 STA-15B

JOA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

MGG03045001

Date/Time

25/MAY

of Collection

12500 (PDT)

Test Location:

Longitude

150 45.91N

Torque Indicator

Serial Number 2249

Date/Time

25/MAY

of Testing

1415 (PDT)

Box Core

Retrieval Depth:

4515 METERS

Latitude

126 04.4W

Longitude

00.51W

Vane Size

14

Box Core 50

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	1-8	1714	0-8	1	1476	0-8	1	1476	0-6
10 cm	2-12	1309	1	1	1476	0-12	2-2	10115	0-12
20 cm	3	1428	1-4	3	1595	1-4	2-2	10115	0-14
30 cm	2-12	1309	1	1	1476	2-6	2-8	119	1-4
40 cm									
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						COKE 38 CM DEEP
B						SMALL nodules
C						uniform color
D						SIDE PICTURE TAKEN
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

Box Core
Number 43-15 STA-16B

NOAA CRUISE (MAY 19/5)
VANE SHEAR DATA SHEET

MGG03045001

Date/Time 23 MAY
of Collection 2215 (PDT)

Test Location: Longitude 15° 45' 45" N
Latitude 126° 0' 0" W

Torque Indicator
Serial Number 2249

Date/Time 24 MAY
of Testing 0055 (PDT)

Box Core
Retrieval Depth: 45.38 METERS

Vane Size 1"

Box CORE 43

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	1	.476	0-8 1238	1	.476	0-6 .1785	1-4 .595	0-4 .119	
10 cm	1-14	.8925	0-10 .2975	1-9	.7430	0-8 .238	2 .952	0-8 .1238	
20 cm	2-14	1.3685	1-2 .5355	2	.952	0-14 .4165	2-7 1.0163	1-4 .595	
30 cm	2-10	1.2495	1-4 .595	2-11	1.23	1-2 .5355	2-2 1.0115	1 .476	
40 cm				2	.952	1			
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A	~					CORE 50 CM DEEP
B						SOME LARGER NODULES
C						UNIFORM COLOR
D						
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

Box Core
Number 44-16-STA-16B

NOAA CRUISE (MAY 1975)
VANE SHEAR DATA SHEET

MGG03045001

Date/Time 24 May
of Collection 0858 PDT

Test Location: Longitude 15°46.7'N
Latitude 126°09.7'W

Torque Indicator
Serial Number 2249

Date/Time 24 May PDT
of Testing 0445

Box Core
Retrieval Depth: 4628 METERS

Vane Size 1"

Box Core 44

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	1-8	.714	0-8				1-8	.714	0-8
10 cm	1-14	.8925	0-8				1-12	.833	0-8
20 cm	2-4	1.071	1				2	.952	0-12
30 cm	2-12	1.309	1				3	1.428	1
40 cm	2-4	1.071	1				2-4	1.071	1
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE DEPTH 50 CM
B						TOP OF CORE WAS
C						Perturbed for a few
D						cm so first 5 cm
E						MAY NOT BE GOOD

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

A FEW SMALL NODULES ON TOP.

Tested by: _____

Box Core 45
Number 7A STA-16B

NOVA CRUISE (MAY 1970)

MGG03045001

VANE SHEAR DATA SHEET

Date/Time 24 MAY
of Collection 0628 (PDT)

Test Location: Longitude 150° 43' 7" W
Latitude 126° 47' 2" W

Torque Indicator
Serial Number: 2-2-47

Date/Time 28 MAY
of Testing 0810 (PDT)

Box Core
Retrieval Depth: 4648 METERS

Vane Size 1"

BOX CORE 45

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
		in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI			
5 cm	0-14	4165	0-6	1785	1-2	5355	0-8	238	1-10	17235	0-10	17235
10 cm	2-4	1071	1-2	5355	2	952	1	476	1-12	1833	0-14	4165
20 cm	2-4	1071	1-2	5355	2-2	10115	1	476	2-10	12495	1-8	17235
30 cm	2-10	12495	1-4	595	2-8	119	1-4	595	2	952	1-2	5355
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 37 cm DEEP
B						FEW NODULES
C						EVEN COLOR
D						
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

Box Core
Number 4648 STA-16B

Date/Time 24 MAY
of Collection 0930 (PDT)

Date/Time 24 MAY
of Testing 1105 (PDT)

NOAA CRUISE (MAY 19/0)

VANE SHEAR DATA SHEET

MGG03045001

Torque Indicator

Serial Number 2249

Test Location: Longitude 15°45'N

Latitude 126° 12' W

Box Core

Retrieval Depth: 4651 METERS

Vane Size 1"

Box Core 46

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
5 cm	1-4	1595	0-10	2995	1-2	15355	0-6	1785	1-6	16545	0-6	1785
10 cm	2	952	0-12	357	2	1952	0-12	1359	3	1428	1	476
20 cm	2-10	12495	1	1476	2-12	1309	1-4	1595	2-4	1071	0-4	14165
30 cm	2-2	10115	1	476	2-2	10115	1	476	1-14	8925	0-14	4165
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A	"					CORE 41 CM DEEP
B						SOME SMALL NODULES
C						LOOKED LIKE THE CORE
D						WAS DISTURBED ON TOP
E						PROBABLY PULLED UP
						BOX CORE WITH ANGLE
						ON IT.

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

Box Core Number 4719 STA-16B

NOVA CRUISE (MAY 1970)
VANE SHEAR DATA SHEET

MCG03045001

Date/Time 24/MAY
of Collection 1237 (POT)

Test Location: Longitude 44.0°N
15°44.5'N
Latitude 126°40.6'W
8.1'W

Torque Indicator
Serial Number 2249

Date/Time 24 MAY
of Testing 1355 (POT)

Box Core
Retrieval Depth: 4660 M

Vane Size 1"

Box Core 47

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
		in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI			
5 cm	1-10	.7735	0-6	.1785	1-10	.7735	0-8	.238	1-8	.714	0-10	.2975
10 cm	2-6	1.1305	0-10	.2975	2	.952	0-10	.2975	2-4	1.071	0-12	.135
20 cm	2	.952	0-10	.2975	2-6	1.1305	0-10	.2975	2-10	1.248	0-12	.135
30 cm	2-14	1.3685	1-4	.595	2-10	1.2495	1	.476	3	1.428	1-6	.165
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						COKE 41 CM DEEP
B						SMALL nodules
C						EVEN COLOR
D						
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

Box Core
Number 4920 STA 16B

Date/Time 24/MAY
of Collection 1950 (PDT)

Date/Time 24/MAY
of Testing 8/30 (PDT)

WAVE CRUISE (MAY 1950)
VANE SHEAR DATA SHEET

MGG03045001

Test Location: Longitude 150°46.7'N
Latitude 150°0'0" W ✓

Torque Indicator
Serial Number 2249

Box Core
Retrieval Depth: 4692 meters Vane Size 1"

Box Core 49

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
				in-lb	PSI	in-lb	PSI	in-lb	PSI			
5 cm	1-2	.5355	0-6	.1785	1	.476	0-6	.1785	0-4	.595	0-8	.1714
10 cm	2-4	1.091	0-14	.4165	2-2	1.0115	0-14	.4165	1-12	.833	0-12	.833
20 cm	2-8	1.19	1-4	.595	2-10	1.2495	1-4	.595	2-8	1.19	1-4	.595
30 cm	2-8	1.19	1-4	.595	2-8	1.19	1	.476	2-6	1.1305	1-2	.5355
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 40 CM DEEP
B						UNIFORM COLOR AND
C						THICKNESS, FEW
D						Small nodules
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

(Use back side for additional comments)

STA 18

Box Core
Number 31 LARGE

Date/Time 20/MAY
of Collection 1440 (PDT)

Date/Time 20/MAY
of Testing 1645 (PDT)

NOAA CRUISE (MAY 1975)
VANE SHEAR DATA SHEET

MGG03045001

Torque Indicator
Serial Number 2249

Box Core
Retrieval Depth: 4402 METERS
Vane Size 1"

Test Location: Longitude 15° 14' 51" N
Latitude 125° 59' 21" W

Box Core 31

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	3-14	1.8345	1-8	5-4	2.489	2	2-6	1.1305	1-6 .6545
10 cm	5-14	2.7865	2-4	5	2.37	2-4	4-12	2.251	1-14 .8925
20 cm									
30 cm									
40 cm									
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 17 CM DEEP
B						DEEP RED COLOR, VERY
C						FIRM TOP AND INSIDE,
D						FEW NODULES ON
E						TOP

Vane was penetrated from ☐ side ☒ top of box core sample.

Sleeve ☒ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

(Use back side for additional comments)

STA-18

Box Core

Number 325 LARGE

NOAA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

MGG03045001

Date/Time of Collection 20 MAY 1825 (PDT)Test Location: Longitude 15° 14' 5" N
Latitude 125° 58' 2" WTorque Indicator
Serial Number 2249Date/Time of Testing 20 MAY 2006 (PDT)Box Core
Retrieval Depth: 4423 METERSVane Size 1"

Box Core 32

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
		in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI			
5 cm	1-2	1.5355	0-8	.238	0-14	.4165	0-8	.238	1-4	.595	0-8	.238
10 cm	2	.9520	1-2	.5355	2-4	1.08	1-4	.595	2-4	1.08	0-14	.4165
20 cm	2-8	1.19	1-2	.5355	2-14	1.3685	1-6	.6545	2-12	1.309	1-4	.595
30 cm	3-10	1.7155	1-6	.6545	4	1.894	1-6	.6545	4-14	2.3105	1-12	.8330
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 37cm DEEP
B						UNIFORM in color
C						SOME small nodules
D						
E						

Vane was penetrated from ☐ side ☒ top of box core sample.Sleeve ☒ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

(use back side for additional comments)

STA 18

Box Core
Number633
LARGE

NOAA CRUISE (MAY 1975)

MGG03045001

VANE SHEAR DATA SHEET

Date/Time

20 MAY

of Collection 2150 (PST)

Test Location:

Longitude 150° 14' 15" N

Latitude

126° 00' 10" W

Date/Time

20 MAY

of Testing 2315 (PDT)

Box Core

Retrieval Depth:

4383 METERS

Vane Size

1"

Torque Indicator

Serial Number 2249

Box Core 33

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	0-12	.357	0-4	.119	0-14	.4165	0-12	.357	0-4
10 cm	2-4	1.091	1-4	.595	2	.952	2-2	1.0115	1-2
20 cm	2-2	1.0115	1-2	.5355	2	.952	1-14	.8925	1-6
30 cm	3-14	1.8345	1-12	.833	2-2	1.0115	2-14	1.3685	1-10
40 cm									
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 36 CM DEEP, FEW SMALL NODULES
B						Uniform in color
C						
D						
E						

Vane was penetrated from ☐ side ☒ top of box core sample.Sleeve ☒ was ☐ was not used on wave shaft during testing.

Comments:

Tested by:

(use back side for additional comments)

Box Core
Number

Large
34

Date/Time of Collection 21 May 2017 (PDT)

Date/Time
of Testing

Box 107
m

NOAA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

21 MAY (POT)
0117

21 MAY (PAT)
0230

MCG03045001

19.2.12

Torque Indicator
Serial Number 2249

Vane Size _____

Test Location: Longitude 15° 44' N
Latitude 126° 20' 24" W

Box Core
Retrieval Depth: 4375 meters 00.5'W

[illegible]

Special Locations	Depth from top of sediment (cm)	P		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 40 CM DEEP
B						FEW SMALL NODULES
C						
D						
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by:

(use back side for additional comments)

STA 18

Box Core Number 358 LARGE

Date/Time of Collection 21 MAY 0425 (PDT)

Date/Time of Testing 21 MAY 0640 (PDT)

NOAA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

MGG03045001

Test Location: Longitude 15° 14' 00" N
Latitude 125° 04' 11" W

Torque Indicator Serial Number 2249

Box Core Retrieval Depth: 4365 METERS

Vane Size 1"

Box Core 35

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
5 cm	1-6	.6545	0-10	.2975	1-2	.5355	0-6	.1785	1	.476	0-6	.1785
10 cm	2-4	1.071	0-14	.4165	2-4	1.071	1	.4760	2-12	1.309	1-2	.5355
20 cm	3-4	1.537	1-4	.575	3-2	1.4875	1-2	.5355	3-4	1.537	1-4	.575
30 cm	2-2	1.0115	1-2	.5355					2-12	1.309	1-6	.6545
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 37CM DEEP
B						
C						
D						
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

(Use back side for additional comments)

STA 18

Box Core
Number

37-9 LARGE

NOAA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

MGG03045001

12.2'N

150°16.7'W

Date/Time

21 MAY

of Collection 2322 (PDT)

Test Location:

Longitude

Latitude

Torque Indicator

Serial Number

Date/Time

22 MAY

of Testing 0130 (PDT)

Box Core

Retrieval Depth:

4447 METERS

Vane Size

1"

Box CORE 37

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	1	.476	0-4	.119	1	.476	0-4	.119	1
10 cm	1-12	.833	0-12	.357	1-14	.8925	1	.476	1-14
20 cm	2	.952	0-12	.357	2-6	1.1305	1	.476	2
30 cm	2-10	1.2495	1-2	.5355			2-14	1.3685	1-4
40 cm									
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 39 CM DEEP
B						MEDIUM + SMALL NODULES
C						MUD LIGHT BROWN DOWN
D						TO 25CM FROM TAKE
E						DOWN DARK BROWN

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

SIDE PHOTO TAKEN

Tested by:

(use back side for additional comments)

STA-20

Box Core
Number

27-1

(Large Core)
50 cm sq

NOAA CRUISE (MAY 1975)
VANE SHEAR DATA SHEET

15° 51.2' N
150° 58.39' W

DOMES PROJECT
RP-6-OC-75 keyz

20

Date/Time
of Collection

16/MAY 1975
1345 (PDT)

16/MAY 1975

Test Location: Longitude
Latitude

11.6' W

Torque Indicator
Serial Number

2249

Date/Time
of Testing

16/MAY 1975
1530 (PDT)

16/MAY 1975

Box Core
Retrieval Depth:

4702 METERS

Vane Size

1"

STA 20 BOX CORE 27

MGG03045001

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	1-6	.6545	602			.1785			
10 cm	1-12	.833	1			.476			
20 cm	1-14	.8925	1-6			.6545			
30 cm	1-14	.8925	1-6			.6545			
40 cm									
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						DEPTH OF CORE 37CM
B						color was uniform with
C						slight marbling,
D						small nodules
E						

Vane was penetrated from ☐ side ☒ top of box core sample.

Sleeve ☒ was ☐ was not used on wave shaft during testing.

Comments:

Tested by:

(use back side for additional comments)

STA 23B

Box Core 3³⁰ Small
Number

NOAA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

Date/Time 20/MAY
of Collection 0923 (PDT)Date/Time 20/MAY
of Testing 1045 (PDT)Test Location: Longitude 14° 45.9' N
Latitude 125° 58.6' WTorque Indicator
Serial Number 2249Box Core
Retrieval Depth: 4860 METERS
Vane Size 1"Box Core 30

MGG03045001

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3		
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual
	in-lb	PSI		in-lb	PSI		in-lb	PSI	
5 cm	0-10	.2975	0-6		.1785				
10 cm	1-10	.7735	0-12		.357				
20 cm	2	.952	0-14		.4165				
30 cm	2-10	1.2495	1-6		.6545				
40 cm	2-4	1.08	0-14		.4165				
50 cm									

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 48CM DEEP
B						FEW small nodules on
C						TOP - SLIGHT MARBLING
D						on side, mud light
E						Brown in color, muddy
						on top, unable to
						get photo of side.

Vane was penetrated from ☐ side ☒ top of box core sample.Sleeve ☒ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

(use back side for additional comments)

STA 24B

Box Core
Number 29-2 Large

Date/Time 19/may (PDT)
of Collection 1420

Date/Time 19/may (PDT)
of Testing 1605

NOAA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

Box Core
Retrieval Depth: 14,280'

Test Location: Longitude 14° 15' 40" W
Latitude 126° 00' 10" W

Torque Indicator
Serial Number 2249

Vane Size 1"

(Box core 29)

MGG03045001

Depth of Penetration from top of sediment	VS-1				VS-2				VS-3			
	P _{max}		Residual		P _{max}		Residual		P _{max}		Residual	
	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI
5 cm	2	.952	1402	.4165								
10 cm	2	.952	1	.4760								
20 cm	2-12	1.309	1-6	.6545								
30 cm	2-4	1.08	1-2	.5355								
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 32 CM DEEP
B						unif. color. with
C						slight lighter color
D						marbling
E						

Vane was penetrated from ☐ side ☒ top of box core sample.

Sleeve ☒ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

STA-25

Box Core
Number

22 51

NOAA CRUISE (MAY 1975)

VANE SHEAR DATA SHEET

MGG03045001

Date/Time

27 MAY

Date/Time

20 MAY (PDT)

of Collection

1136 (PDT)

Test Location:

Longitude 140 14.5'N

Latitude

1240 57.6'N

Date/Time

20 MAY (PDT)

Date/Time

20 MAY (PDT)

of Testing

1315 (PDT)

Box Core

Retrieval Depth: 4696 METERS

Retrieval Depth:

4696 METERS

Torque Indicator

Serial Number 2289

Vane Size

1"

Box Core 51

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
5 cm	4-6	2.0725	1-8	1.714	2-10	1.2495	0-14	1.4165	2-12	1.309	1-4	1.595
10 cm	4-10	2.1915	1-4	1.595	5-10	2.6695	2-2	1.0115	5-12	2.727	1	1.476
20 cm	4-4	2.013	1	1.476	5-8	2.608	1-10	1.7235	4-14	2.3105	1-2	1.5355
30 cm												
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 32cm DEEP
B						FEW SMALL nodules
C						DARK RED COLOR
D						CRUMBLY AND SOFT
E						SIDE PICTURE TAKEN

Vane was penetrated from ☐ side ☐ top of box core sample.Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

(use back side for additional comments)

Box Core STA. #27
Number 2352

NOAA CRUISE (MAY 1975)
VANE SHEAR DATA SHEET

MGG03045001

Date/Time 28 MAY
of Collection 0950 (PDT)

Test Location: Longitude 16° 00.5' N
Latitude 124° 59.6' W

Date/Time 28 MAY
of Testing 1130 (PDT)

Box Core Retrieval Depth: 4376 meters

Torque Indicator
Serial Number 2249

Vane Size 1"

Box Core 52

Depth of Penetration from top of sediment	VS-1			VS-2			VS-3					
	P _{max}		Residual	P _{max}		Residual	P _{max}		Residual			
	in-lb	PSI		in-lb	PSI		in-lb	PSI				
		in-lb	PSI	in-lb	PSI	in-lb	PSI	in-lb	PSI			
5 cm	0-14	0.4165	0-4	.119	1-2	.5355	0-8	.238	1-6	.6545	0-10	.2975
10 cm	2-4	1.071	0-14	.4165	2-2	1.0115	1	.1476	2-8	1.19	0-12	.359
20 cm	2-6	1.1305	1	.1476	2-6	1.1305	1-2	.5355	2	.952	1	.1476
30 cm												
40 cm												
50 cm												

Special Locations	Depth from top of sediment (cm)	P _{max}		Residual		Sediment Description Color, Texture, etc.
		in-lb	PSI	in-lb	PSI	
A						CORE 33 CM DEEP
B						SAND NODULES
C						MEDIUM BROWN
D						
E						

Vane was penetrated from ☐ side ☐ top of box core sample.

Sleeve ☐ was ☐ was not used on wave shaft during testing.

Comments:

Tested by: _____

Original

VANE SHEAR TEST PROCEDURES
DOMES CRUISE, LEG III, 1975.

MGG 0 3 0 4 5 0 0 1

Vane Shear Test Equipment and Procedures

A hand-held vane shear device, fabricated at Lockheed, was utilized to measure the sediment strength. The device consists of a snap-on torque wrench (0-192 in-oz torque range) attached to a 28 in. long stainless steel, sleeved shaft with a vane blade. One of two sizes of vanes was used for testing, depending on the stiffness of the sediment. Softer sediment cores were usually tested with either a 1 in. or $1\frac{1}{2}$ in. (height and diameter) vane, while stiffer sediment cores were always tested with the 1 in. vane, so as not to exceed the range of the torque meter. A vane rotation rate of approximately 3 rpm was found optimum to minimize ship's motion effects during testing.

Testing of each box core consisted of making three separate vane shaft insertions and, on each insertion, measuring the original and remolded vane shear strength at successive 3 in. depth intervals through the length of the core.

Note: Remolded vane shear values were obtained by rotating the vane 360° and then measuring the shear strength.

Explanation of terms used on Vane Shear Data Sheets:

VS-1	- Test 1
VS-2,-3	- Replicates
P _{max}	- original, undisturbed test
Residual	- remolded test
conversion factor (ex. 0.48)	- PSI= (in-lbs)(0.48)

Original

MGG 03043002

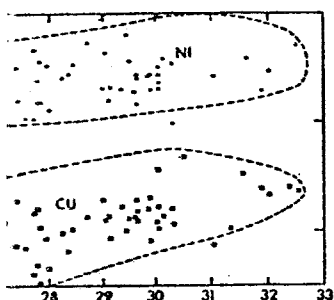
2

INDEX OF BOX CORES

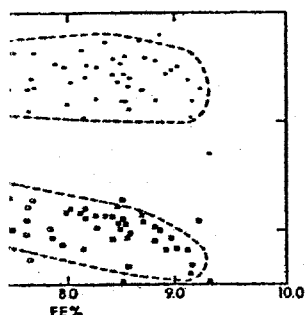
DOMES PROJECT

Cruise RP-6-OC-75--Legs 1 & 2

Box Core No.	Date	Time	Ship Station	Site Location	North Latitude	West Longitude	Water Depth Corr.
27	75 05 16	1345	20	C	15°59.3'	126°11.6'	4702 m.
29	75 05 19	1420	24B	C	14°15.4'	126°01.4'	14280 ft.
30	75 05 20	0923	23B	C	14°45.9'	125°58.6'	4860 m.
31	75 05 20	1440	18	C	15°14.7'	125°59.0'	4402 m.
32	75 05 20	1825	18	C	15°14.9'	125°54.8'	4423 m.
33	75 05 20	2150	18	C	15°14.0'	126°00.4'	4383 m.
34	75 05 21	0117	18	C	15°14.2'	126°00.5'	4375 m.
35	75 05 21	0425	18	C	15°14.4'	126°00.1'	4365 m.
37	75 05 21	2322	18	C	15°12.2'	125°58.6'	4447 m.
38	75 05 22	0528	14	C	15°13.6'	126°30.4'	4526 m.
39	75 05 22	0840	14	C	15°14.6'	126°29.6'	4581 m.
40	75 05 22	1146	14	C	15°15.5'	126°29.1'	4500 m.
41	75 05 22	1531	14	C	15°15.1'	126°29.3'	4559 m.
42	75 05 22	1836	14	C	15°15.9'	126°28.1'	4636 m.
43	75 05 23	2215	16B	C	15°45.5'	126°10.6'	4538 m.
44	75 05 24	0258	16B	C	15°46.7'	126°09.7'	4628 m.
45	75 05 24	0628	16B	C	15°44.0'	126°10.1'	4648 m.
46	75 05 24	0930	16B	C	15°45.5'	126°11.8'	4651 m.
47	75 05 24	1237	16B	C	15°44.0'	126°09.1'	4660 m.
49	75 05 24	1950	16B	C	15°46.7'	126°11.2'	4692 m.
50	75 05 25	1255	15B	C	15°45.6'	126°00.5'	4515 m.
51	75 05 27	1136	25	C	14°14.5'	124°58.5'	4696 m.
52	75 05 28	0950	27	C	16°00.5'	124°59.6'	4376 m.
53	75 05 29	1346	11	C	16°0.7'	126°46.30'	4585 m.



Weight percent Cu, vs weight percent Mn.



Cu vs Fe. Note decrease in Cu with increasing Fe.

Cu + Ni and lower in Fe content than smaller nodules regionally. This problem is discussed more fully in the next section.

TURE OF

Nodules recovered by the *Challenger* expedition proposed a widely accepted terminology or variety of nodules recovered from the deep sea. A classification scheme based on nodule size, composition, and internal structure. Many nodules, however, do not fit into any one category. This is due to the apparent morphological variability of the nodules. The need for a brief, unambiguous, and concise description of manganese nodules. Nodules are classified by size, shape, and surface texture, with no attempt at

internal description or inferred genesis (Table 5). Frequently nodules are difficult to separate into distinct categories, in which case they may be jointly classified.

A summary table of nodules recovered by Nodule Project cruises (Mn-74-01, Mn-74-02) shows the regional occurrence of nodule types (Table 6). The frequency

Table 5 Field classification of Mn nodules^a

Prefix	Primary Morphology	Suffix
<i>s</i> = small = <3 cm nodule	[S] = Spheroidal [E] = Ellipsoidal	<i>s</i> = smooth (smooth or microgranular)
<i>m</i> = medium = 3-6 cm size	[D] = Discoidal (or tabular-discoidal form)	<i>r</i> = rough (granular or microbotryoidal) surface texture
<i>l</i> = large = >6 cm maximum diameter	[P] = "Poly" (coalspheroidal or botryoidal form) [B] = Biological (shape determined by tooth, vertebra, or bone nucleus) [T] = Tabular [F] = Faceted (polygonal form due to angular nucleus or fracturing)	<i>b</i> = botryoidal

^a Examples: *l*[D]*b* = large discoidal nodule with botryoidal surface; *m-l*[E]*r-b* = medium-to-large ellipsoidal nodules with smooth tops, rough-to-botryoidal bottoms.

Table 6 Relationship between nodule morphological type and sediment type. Data based upon cruises illustrated in Figure 1 (from J. D. Craig, in preparation)

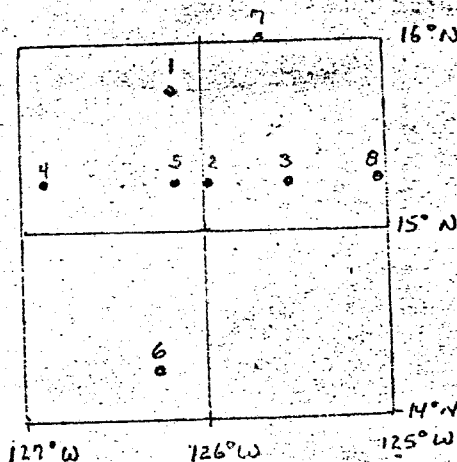
Siliceous region		Red clay region		Nodule type
Number of nodules	%	Number of nodules	%	
262	37.5	76	20.9	D
144	20.6	42	11.6	E
129	18.6	33	9.1	S
131	18.8	27	7.4	P
17	2.4	178	49.0	F
8	1.1	1	0.3	B
7	1.0	6	1.7	T
698	100.0	363	100.0	

Camera Station Locations - DOMES Cruise RP-6-OC-75

At each of eight stations approximately 500 vertical photographs of the seafloor were taken on a single 100-foot roll of Tri-x film. Four to five hours were needed to complete each operation including approximately 75 minutes of actual sea-floor photography. Exposures were made at 8-second intervals while maintaining the supporting wire in a vertical attitude. This usually resulted in a movement across the sea-floor of about $\frac{1}{2}$ to 1 knot depending on the existing ocean currents and wind. A vane compass with overall length of 13 inches and a vane length of 10 inches was suspended 9 feet below the camera lens.

Position information was obtained from the Navy Satellite System; satisfactory fixes were obtained at intervals of up to 3 or 4 hours thus assuring a minimum of one fix per camera station. From this information, dead reckoned positions for the ship at the beginning of each period of photography was determined.

Camera Station	Ship Station	Date (GMT)	Time (GMT)	Latitude	Longitude
1	2	April 24, 1975	1727	15° 45.5'N	126° 10.0'W
2	4	April 27	0334	15° 15.1'N	125° 59.2'W
3	5	April 28	1707	15° 16.5'N	125° 31.4'W
4	8	April 30	1328	15° 16.4'N	126° 52.0'W
5	9	May 1	2043	15° 16.6'N	126° 09.2'W
6	6	May 2	1339	14° 17.5'N	126° 15.4'W
7	1	May 3	0855	16° 01.5'N	125° 40.3'W
8	10	May 3	1845	15° 15.3'N	125° 01.5'W



20°
180° DOMES 110°
5°

original
INDEX OF BOX CORE PHOTOS

DOMES Program

RP-6-OC-75 -- Legs 1 & 2

03045001 5

MGG 03045001

Site C Sta 3

1. Box core 5/5 - top view
2. Box core 5/5 - top view with subcores

3. Box core 5/5 - top view with subcores

Sta 5

4. Box core 2/10 - top view subcores

5. Box core 2/10 - top view with subcores

Sta 6

6. Box core 1/16 - top view

7. Box core 4/19 - top view

Sta 9

8. Box core 1/21 - top view
9. Box core 1/21 - top view with subcores

10. Box core 3/23 - top view

Sta 20

11. Box core ____ - top view

Sta 24B

12. Box core ____ - top view

13. Box core ____ - top view with subcores

Sta 23B

14. Box core 30 - top view

Sta 18

15. Box core 1/31 - top view
16. Box core 2/32 - top view
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- 54. Box core 24/53 - top view

**For stations 3, 5, and 6, photo's 1 through 7, the scale shown in the photographs should be labeled as units of $\frac{1}{2}$ inch not centimeters. The scale in the other photos are correct.*

7

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Domes Vane Shear data for RP-6-OC-75
Person to contact if any further documentation is needed:

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DEEP OCEAN MINING ENVIRONMENTAL STUDY
(DOMES)
LITERATURE SURVEY

February 1977

Prepared by:
DOCUMENTATION ASSOCIATES INFORMATION SERVICES INCORPORATED

Prepared for the National Oceanic and Atmospheric Administration,
Department of Commerce, under Contract No. 03-6-022-35178 by
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ACKNOWLEDGEMENTS

We wish first to acknowledge the assistance and guidance of Dr. Robert E. Burns, our Project Officer at the Pacific Marine Environmental Laboratory (PMEL) under the MESA program.

We would like to thank our consultants, who provided the necessary scientific guidance to make this project possible, and who took responsibility for the sections on physical, chemical, geological, and biological oceanography. We relied heavily on their subject expertise. Using the references we collected, they assisted in selecting the papers to be discussed in each section, suggested additional references, and reviewed the successive drafts of the text for scientific accuracy.

These consultants included:

Physical Oceanography: Dr. J.L. Reid, Scripps Institution of
Oceanography

Chemical Oceanography: Dr. I.R. Kaplan, University of California
at Los Angeles

Geological Oceanography: Dr. D.S. Gorsline and Mr. P.C. Day,
University of Southern California

Biological Oceanography: Dr. J. Hirota, University of Hawaii;
Dr. R.R. Hessler (Deep-Water Benthos), and
Dr. W.L. Newman (Shallow-Water Benthos),
Scripps Institution of Oceanography

Our deepest thanks go to Dr. Jed Hirota, who in addition to the above, served as the senior scientific editor. He read and commented on the entire text, reviewed all references for the bibliography, and participated in decision-making regarding format, style, and organization. His interest

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in the project, particularly his dedication to the comprehensiveness of the literature search and to the scientific accuracy of the narrative survey, was an inspiration to all of us who worked with him.

This literature survey was conducted and prepared by Documentation Associates in Los Angeles, California, under the direction of Ms. Marianne Moerman, who coordinated the entire project, edited the text, and compiled the bibliography. Computer data base searching was performed by Ms. Janis Brown; manual library searching was carried out by Ms. Julie Moore and supporting staff. Dr. Claire Eves was the primary technical writer on the project, assisted by Ms. Joan Segal (geological oceanography) and Mr. Michael McConnel (physical oceanography). The production staff included Ms. Gayle Kleiman, Mr. Garrie Bateson, who typed the text and bibliography, and Mr. Peter Schneider, editor.

Date

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INTRODUCTION

HISTORICAL BACKGROUND

Ferromanganese deposits were first discovered by the Challenger Expedition in the 1870's, over one hundred years ago. At the turn of the century, the U.S. Albatross brought up nodules from the eastern Pacific Ocean floor. Little further investigation was accomplished, however, until the International Geophysical Year, in 1957 and 1958, when the Scripps Institution of Oceanography dredged and took deep-sea photographs throughout the eastern Pacific. A cooperative project was established, involving the Institute of Marine Resources at Scripps and the Department of Mineral Technology, to study the commercial possibilities of mining nodules. The project's findings are summarized by Mero (1960). Five years later, Mero (1965) compiled existing data on the chemistry and distribution of manganese nodules, and further showed their potential economic importance due to the copper, nickel and cobalt included in their structure.

NSF-IDOE MANGANESE NODULE PROJECT

Interest in ferromanganese deposits increased and broadened, leading to the establishment in 1972 of the Manganese Nodule Project of the Seabed Assessment Program, funded by the National Science Foundation through the Office of the International Decade of Ocean Exploration (IDOE). The National Advisory Committee on Oceans and Atmosphere (1975) published a midterm review of the IDOE program. The IDOE has produced 5 progress reports, the latest in October 1976

(NOAA Environmental Data Service, 1976). This discusses the Manganese Nodule Project and includes a bibliography of the most recent studies published. The Manganese Nodule Project, first named the Inter-University Program of Research on Ferromanganese Deposits on the Ocean Floor, was initiated at the Arden House Conference/Workshop, January 20-22, 1972. The published conference proceedings (Horn, 1972) include thirty scientific papers on topics including origin and genesis, distribution, mining, and economic potential of ferromanganese nodules. The conference goal was to bring together current information on ferromanganese deposits in the ocean environment. The Inter-University Program published its Phase I Report in April, 1973. The Manganese Nodule Project Coordinators Office, which issues quarterly progress reports to IDOE, was set up first at Lamont-Doherty Geological Observatory at Columbia University but moved to the Scripps Institution of Oceanography in 1975.

The Project has organized workshops (most recently in Seattle, Washington, March 3-5, 1976) and issued conference proceedings. A symposium-workshop on manganese nodule deposits in the Pacific was held in Hawaii, October 16-17, 1972 (Hawaii Department of Planning and Economic Development, 1973), at which 18 technical papers on legal, technological and industrial aspects were presented, as well as an evaluation session and assessment workshop. The following year an international symposium was held in Hawaii, July 23-25, 1973, organized by the Valdivia Manganese Exploration Group and the Hawaii Institute of Geophysics. Over 20 papers of the conference were published under the editorship of Morgenstein (1973) and covered subjects such as the geochemistry and mineralogy of manganese nodules, nodule facies, exploration, geochemical and environmental problems of nodule genesis, and future

aspects of international cooperation. The program enjoys strong international cooperation. in particular with Kennecott Exploration, Inc.; Ocean Resources, Inc.; the West German Valdivia Group; and the French CNEXO. International interest continues in Germany and France, as well as in other industrialized countries including Japan, Russia and Canada.

Technical reports have been issued since the start of the NSF-IDOE project. Technical reports 1 and 2 were published in the first year of the project (Horn et al., 1972; Frazier and Arrhenius, 1972). The most recent three at this writing are: (1) technical report no. 12 (Monget et al., 1976) compiling published multicomponent/analyses of ferromanganese concretions, (2) technical report no. 13 (Greenslate and Gerard, 1976) on the BOMDROP Expedition MN-75-03 of the R/V Kana Keoki, and (3) technical report no. 14 (Meylan et al., 1976), a significant literature survey in itself. Meylan consists of a bibliography and index to the literature on manganese nodules (1874-1975) and acts as a key to the extant data in the field up to 1975. The bibliography consists of 1734 entries and numerous indexes subdivided into 26 major categories, both geographical and topical. Topics include chemical composition, distribution, mineralogy and physical properties of sediments, geochemistry and geochemical processes, formation and origin, internal structure, growth rates, economic potential, and environmental and legal aspects of mining.

PUBLIC AND CONGRESSIONAL INTEREST

As papers continue to be published in the open literature and presented at congresses, workshops and symposia, and annual meetings of

professional associations, there is a continuing need for the compilation of bibliographic information, whether in printed form or on magnetic tape. This is true whenever a new topic of concern receives the attention of researchers and the general public. Computerized files including both published and unpublished data on manganese nodules are established at many locations. For instance, there are both very specific and small-scale ones such as the Scripps Institution of Oceanography data base on manganese nodules, set up by Jane Frazer, and very general and large-scale ones such as NOAA's National Oceanographic Data Center in Boulder, Colorado. There is considerable interest in manganese nodules both in industrial and congressional realms. The Committee on Interior and Insular Affairs (U.S. Congress. Senate. 1973; U.S. Congress. House. 1974) has held hearings on mineral resources. The Interagency Committee on Marine Science and Engineering (1975), working through NOAA's Environmental Data Service, has prepared a committee print on ocean data resources for the use of the Senate Committee on Commerce. Most recently, a committee print on ocean manganese nodules (Mielke, 1976) was prepared by the Congressional Research Service of the Library of Congress.

PROJECT DOMES

This nationwide and scientific interest in ferromanganese deposits has led the National Oceanic and Atmospheric Administration (NOAA), under the U.S. Department of Commerce, to fund a Deep Ocean Mining Environmental Study (DOMES). DOMES is a multidisciplinary research effort undertaken to identify the potential marine environmental impact that could be expected to result from the commercial-scale mining of

deep-ocean ferromanganese deposits. The project was officially begun in 1976, although related field work was conducted in 1974 and 1975. It is managed by the Pacific Marine Environmental Laboratory (PMEL) as a part of NOAA's Environmental Research Laboratories (ERL) under its Marine EcoSystems Analysis (MESA). Phase I, the search for sufficient baseline data to determine the environmental parameters of the mining region, includes both field operations and a survey of relevant literature, both of which are discussed in detail below.

FIELD OPERATIONS

Cruises to the DOMES area were undertaken during 1975 on the NOAA R/V Oceanographer. The Final Data Report on Cruise RP-6-OC-75, Legs 1 and 2, has been issued (Roels et al., 1975). Oceanographer cruises RP-8-OC-75 and RP-8-OC-76, Legs 1-6 have been completed, and Legs 7-10 are scheduled (NOAA. DOMES Project, 1976). Recent manganese nodule-related cruises to the DOMES area, whose data are incorporated into the DOMES Project, include the Kana Keoki cruise during August and September, 1972 (Roels et al., 1973), and the Moana Wave cruise 74-2 during April and May, 1974. This latter cruise was reported on by Amos et al. (1975), and presents a preliminary overview of the baseline conditions in a 24000 km² area over a siliceous ooze province within DOMES. Roels, Amos, and other investigators at the Lamont-Doherty Geological Observatory had for some time been interested in the environmental impact of deep-sea mining for manganese nodules (Roels et al., 1972a, 1972b).

The DOMES Project has issued a project development plan (Wing, 1974) and periodic project progress reports on proposals selected for funding, and on field operations. The principal investigators in Phase I

have issued progress reports; a principal investigator symposium was held in Seattle, December 18, 1975 (Anderson, 1975), followed by a NOAA Marine Minerals Workshop, March 23, 1976 (Anderson, 1976). At this writing, the draft preliminary report for DOMES Phase I has been issued (NOAA. DOMES Project, 1976).

LITERATURE SURVEY

The purpose of the present literature survey is to provide a comprehensive source book of available literature and information about the DOMES area so that persons interested in DOMES can know about and have easy access to types of information and existing data. A compilation of publications on research conducted in the area can assist both the funding agency, by enabling it to avoid unnecessary duplication of research efforts, and the investigators currently involved in the DOMES project.

This report provides a literature survey of important published sources of information about the physical, chemical, geological and biological oceanography of the DOMES area. Literature considered as published material includes those papers accessible through various abstracting and indexing services, including government agencies, technical reports from various institutions, theses and dissertations, and works in foreign languages if abstracts or summaries are available in English. Table 1 presents a list of the bibliographic sources searched manually or by computer, and indicates the years covered by this search. Although certain of the printed indexes are available for earlier years, the realistic constraints of the project limited the search to the years shown, supplemented by cross-checking in major bibliographies and by selected documents provided by the project consultants.

Table 1. List of Bibliographic Sources Searched and Years Covered.

<u>SOURCE SEARCHED</u>	<u>YEARS COVERED</u>
Aquatic Sciences and Fisheries Abstracts	1965 - present (manual search)
Bibliography and Index of Geology (GEOREF)	1967 - present (computer search)
Biological Abstracts (BIOSIS)	1972 - present (computer search)
Biological Information Retrieval System (BIRS)	1955 - present (computer search)
Canadian Marine Fisheries Service List of Translations	1967 - present (manual search)
Chemical Abstracts (CHEMCON)	1970 - present (computer search)
Defense Documentation Center (DDC)	1965 - present (computer search)
<u>Deep-Sea Research</u>	1953 - present (manual search)
Dissertation Abstracts (DATRIX)	1861 - present (computer search)
Engineering Index (COMPENDEX)	1971 - present (computer search)
Environment Abstracts (ENVIROLINE)	1971 - present (computer search)
National Aeronautic and Space Administration Scientific and Technical Reports (NASA-STAR)	1962 - present (computer search)
National Marine Fisheries Service	1971 - present (manual search)
National Technical Information Service (NTIS)	1964 - present (computer search)
Oceanic Abstracts	1964 - present (computer search)
Pollution Abstracts	1970 - present (computer search)
<u>Underwater Information Bulletin</u>	1972 - present (computer search)
Zoological Record	1965 - present (manual search)

From the material gathered in the search, attempts have been made to cite in the text recent review papers when available, work that post-dates the reviews, or is of significant and justified emphasis, and historical and ongoing oceanographic expeditions passing through and working in DOMES. All additional relevant references are presented in the supplementary bibliography.

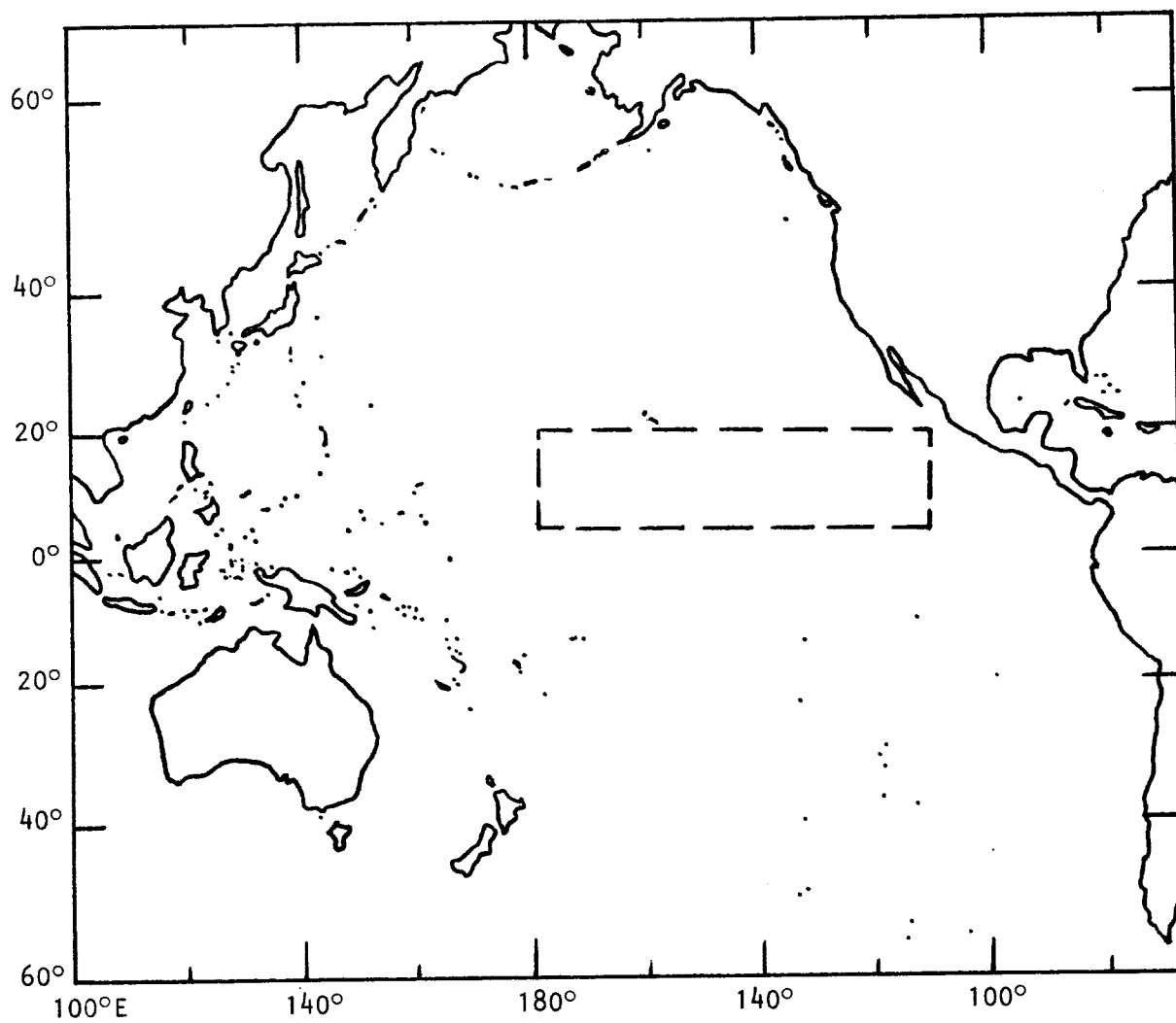
Inclusions. The DOMES area is defined by the 5° - 20° N latitudes, and the 110° - 180° W longitudes (see Fig. 1), the three main longitudinal centers of mining interest being $126^{\circ}15'W$, $138^{\circ}11'W$, and $151^{\circ}8'W$. For this purpose of literature search by geographic area, viz. Biological Information Retrieval System (BIRS), DOMES encompasses Marsden Squares 12-18 and 48-54. The spatial, nongeographical boundaries of this survey (i.e., vertical or bathymetric boundaries) extend from the air space (e.g., for birds) through the air-water interface (e.g., for neustonic and pleustonic zooplankton) and water column, into and including the deep-sea sediments and the benthos.

Studies from the following islands or island systems in DOMES have been included: Johnston Island; Howland and Baker Islands; the Line Islands (consisting of Palmyra, Washington, Fanning and Christmas Islands); the Revilla Gigedo Islands, especially Clarion Island; and Clipperton Island. Also included are the following guyots and seamounts: Horizon, Hess, Agassiz, Allison, Lynn, and California.

Studies judged to be of importance regarding major oceanographic processes or features, although only observed adjacent to or nearby DOMES, or general studies of the tropical Pacific, are included because in many instances either habitat similarity or the nature of scientific

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Figure 1. Deep Ocean Mining Environmental Study (DOMES) Area of Interest



findings from these areas enables the synthesis and extension of results to DOMES. For example, studies of community structure of deep-sea macrobenthos and denitrification outside DOMES may be examined with a view to obtaining insight into this feature and process in DOMES.

Exclusions. Literature has been excluded from this report if it: (1) deals with a geographical area outside the scope of DOMES (except as noted above), (2) repeats material from, or is cited in, a substantial review article in a particular field of research, (3) is of only marginal significance to the DOMES project (e.g., an extrapolation of biogeographic information to the DOMES area, in lieu of actual observation, or (4) deals with one of the topics whose exclusion was agreed upon by the funding agency (NOAA) and Documentation Associates.

Some specific examples of these special topical exclusions are: raw data reports, geophysical work not related to sedimentology or geochemistry, taxonomic and anatomical studies which do not relate the organism to its habitat, mining techniques, popular literature, fish (Osteichthyes and Chondrichthyes, bony and cartilaginous fish), and benthic smothering events, the latter two exclusions being subjects of other literature surveys. In addition, most of the literature specific to the Hawaiian Islands (despite the geographic inclusion criterion of Hawaii, the Big Island) has been excluded because: (1) the extensive studies of its biota and shallow-water ecosystems along the coastlines are not very pertinent to DOMES; (2) in the western region near 151°W mining interests are far to the south of Hawaii toward the equator; (3) oceanographically, Hawaii is near the northern boundary of the North Equatorial Current system and is more strongly influenced by conditions in Northeastern Pacific Central Water than is most of DOMES;

and (4) the large number of references about Hawaii would make this survey unwieldy and contribute very marginally to enhancing the understanding of features and processes in DOMES.

Format. The format and size of the literature survey is designed to be responsive to DOMES' objectives. DOMES Phase I is directed towards acquiring basic data on the character of the environment prior to disturbances by mining, in order to assess the potential impact of deep-sea mining on the marine ecosystem of the north east tropical Pacific. Effects on marine organisms are thus of primary concern. Accordingly, the main body of this survey emphasizes biological oceanography. The briefer supporting sections on physical, chemical and geological oceanography are intended to present what has been published concerning the physical, chemical and geological environment within which these organisms live, and the major physical, chemical and geological processes that explain and control their distribution and abundance.

The main section of narrative text is preceded by this Introduction and a section on Cruises and Expeditions to assist in providing the reader with guidelines and historical perspectives, and is followed by a list of all references cited in the text and a supplementary bibliography.

CRUISES AND EXPEDITIONS

HISTORICAL CRUISES

PRE-WORLD WAR II

POST-WORLD WAR II

RECENT AND ONGOING CRUISES

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CRUISES AND EXPEDITIONS

The cruises which obtained samples or data pertinent to this literature survey include: (1) those which passed through or near DOMES, usually in the course of a circumnavigation survey of the world ocean, Pacific Ocean, or portion thereof; (2) specific investigations confined to limited locales within DOMES (e.g., the Fanning Island Expeditions); and (3) those cruises technically outside DOMES but which collected applicable data. Historical cruises undertaken during the course of now completed expeditions, as well as completed legs of currently ongoing cruises or expeditions, are mentioned herein.

For some of the more important voyages, information about station locations, depth of sampling and type of data retrieved has been summarized in tabular form when this information was available from published sources. However, not all the cruises reported below confined data collection to specific stations. Continuous trawls during an extensive survey cannot be easily assigned to any particular station location. For expeditions entailing numerous and extensive cruises, such as those originating at Scripps Institution of Oceanography, sheer quantity precludes tabulation by station in this survey. However, computer-generated mapping of cruise tracks may be obtained from Scripps. Other cruises mentioned in this literature survey, for which station locations were not available in published sources, had nevertheless entered this information in the ships' logs. Retrieval of such information is possible only by a manual search of the individual pilot logs, and could not be included here.

Until the 1960's, most cruises passing through DOMES were engaged in ecologically-oriented biogeographical surveys of large portions of the ocean.

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The type of sampling regime imposed by the necessity of covering great distances was not well suited to procuring data which defined community structure, functioning and dynamics. From the 1960's through the present, much open-ocean research has been confined to relatively smaller circumscribed regions believed representative of larger habitats, and has involved extensive replicated sampling, measurement, and experiments. Wüst (1964) has discussed the more important historical cruises from 1873 to 1960, in a comprehensive account which includes a bibliography of deep-sea expedition reports.

HISTORICAL CRUISES

PRE-WORLD WAR II

The earliest cruise passing through DOMES was the British Challenger expedition, 1872-76 (Challenger Reports, 1880-1895) throughout the world ocean. Samples were taken from nine stations within DOMES and several others nearby (see Table 2), from the surface waters to depths of 3000 fathoms, or about 5500 m. Wind velocity, currents, water temperature and chemistry, and taxonomic data were compiled. The existence of manganese nodules was noted. The earliest American cruises and expeditions included that of the U.S.S. Albatross of 1891-1905, under the direction of Alexander Agassiz (Agassiz, 1906), conducting marine biological research in the Pacific Ocean.

The American R/V Carnegie passed through DOMES during its 1928-1929 cruise of the Pacific, studying primarily physics, biological distribution of organisms, and sediments (Carnegie Institution, 1942-1945).

The R/V Velero III made numerous cruises of the eastern Pacific during expeditions of the Allan Hancock Foundation (AHF) from 1931 through 1941, when observations were made of the taxonomy, distribution and general ecology of

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Table 2. Sampling and Station Locations of the Challenger Expedition, 1872-1876

<u>Station #</u>	<u>Location</u>	<u>Depth (in fathoms)</u>	<u>Data Taken Includes</u>
260	21°N, 157°W	0-200	Water temp. every 10
261	20°N, 157°W	0-1500, 2050	fathoms (F)
262	19°N, 154°W	0-1500, 2875	from surface
263	17°N, 153°W	0-1500, 2650	to 200 F, then
264	14°N, 152°W	0-1500, 3000	every 100 F
265	12°N, 152°W	0-1500, 2900	to 1500 F;
266	11°N, 152°W	0-1500, 2750	Bottom temp.;
267	9°N, 150°W	0-1500, 2700	Water density
268	7°N, 149°W	0-1500, 2900	at surface,
269	5°N, 147°W	0-1500, 2550	25, 50, 100,
270	2°N, 149°W	0-1500, 2925	200, 300,
271	0°N, 151°W	0-1500, 2425	800 F, and
272	3°S, 152°W	0-1500, 2600	bottom;
			Carbonic Acid
			content;
			Currents;
			Wind velocity;
			Surface organ-
			isms;
			Taxonomy.

fauna. The primary objective of the expedition was to make marine biological investigations, although observations in physical and chemical oceanography, and geology and sedimentation, were also made. Locations in or bordering on DOMES were those around Socorro Island, station numbers 128-133, 289-297, 293-296 (in 1934) and 922-926 (in 1939), and Clarion Island, numbers 134-142, 204, 205, 298-303 (in 1934) and 915-921 (in 1939). The precise coordinates of these stations, giving number, date, locality and bearings, as well as expedition charts, have been published by the Hancock Foundation (Fraser, 1943). AHF cruises collecting benthic organisms have continued off western Mexico since 1948.

These expeditions contributed to basic general understanding of the physics, chemistry, and bottom topography or bathymetry of the oceanic environment as well as the distribution of faunal taxa within DOMES. However, most of the publications mentioned in the present literature review include data obtained during cruises subsequent to World War II.

POST-WORLD WAR II

Dramatic proliferation of oceanographic research occurred in the post-war years. Using the newly-developed piston coring tube, the R/V Albatross collected extensive bottom samples during the 1947-1948 Swedish Deep Sea Expedition (Pettersson, 1957-1959), which included a return to some of the Challenger stations. Samples were taken down to 5800 m at 35 stations within DOMES (stations 72-88, 116-133) and at numerous others nearby. Dredges and trawls were also used. Research included studies of taxonomy and distribution of deep-sea fauna (reported in v. 2), as well as chemical and physical analysis of water (v. 3), bottom investigations (v. 4), and sediment cores (v. 5-9). Sediment cores from the eastern Pacific are described in v. 5. Echograms of bottom topography, as well as bathythermographic profiles of currents, radioactivity, and the occurrence of manganese nodules are included in the reports.

During the 1950-1952 Danish Deep Sea Expedition, the R/V Galathea passed through the DOMES area (Bruun et al., 1956). The objective of the R/V Galathea was to explore the ocean trenches to find out whether life occurs under the extreme conditions prevailing there. Thus, the cruise's primary purpose was to make biological investigations and, secondarily, hydrographic and geomagnetic surveys. The track of the vessel crossed the Pacific from Samoa to Hawaii. No stations were located in DOMES, although station number 710 at 19°N, 105°W, and station number 712 at 17°N, 102°W were close by (Galathea Report, 1957-1973). At these stations, samples were taken at 670 m and 4830 m, respectively. Much of the information obtained aboard the R/V Galathea is taxonomic and zoogeographic in character; however, investigations included phytoplankton, primary productivity, C-14 uptake and photosynthesis. During this expedition the first measurements of autotrophic production were made using the radiocarbon technique developed by Steeman Nielsen, a methodological breakthrough of tremendous significance to subsequent blue water research.

The year 1950 marks the beginning of immense proliferation of oceanographic investigation precluding simple chronological listing. After 1950, research projects consisted typically of multiple expeditions or cruises by one or more research vessels, sponsored by one or several cooperating agencies. The voyage of the R/V Galathea was the last of the single-vessel, single-cruise expeditions of earlier tradition.

The California Cooperative Oceanic Fisheries issue periodic progress reports (CalCOFI atlases) on the data from their cruises. At least four of these are known to have crossed DOMES. Cruises 1, 5, and 9, in 1949, and cruise 20 in 1950, established 40 stations within the DOMES area. Investigations included the distribution of pelagic amphipods, a food source for fishes.

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Beginning in 1950, the Pacific Ocean Fisheries Investigations (POFI), later known as the Bureau of Commercial Fisheries (BCF) in Honolulu, began a series of cruises throughout the Pacific in conjunction with the U.S. Fish and Wildlife Service. These continued through 1969 aboard the R/V Hugh M. Smith, John R. Manning, Charles H. Gilbert, and Townsend Cromwell. The original purpose of these cruises was to investigate the natural history of commercial fish species. Abundance, distribution and biomass were studied as important components of the planktonic food chain. Later cruises sampled and studied neuston and non-fish nekton as well.

Cruises 2, 5, 7, 8, 11, 15, and 16 of the R/V Hugh M. Smith passed through DOMES while traversing the region from 27°N to 14°S between 155°W and 175°W during 1950-1952. All collecting stations for zooplankton on Cruise 16 lay between 1°N and 11°N, and at 150°W or 149°W (see Table 3). From 1951 through 1956, the BCF conducted mid-water trawling from 49°N to 19°S, between 108°W and 162°E. Hugh M. Smith cruises 21, 27-37, John R. Manning cruises 9, 15, 16, 21-24, and Charles H. Gilbert cruises 11-13 crossed the DOMES area.

Subsequently, these BCF and U.S. Fish and Wildlife Service vessels made monthly collections of hydrographic and meteorological data as well as zooplankton from June, 1957, through December, 1958, at the International Geophysical Year station located at 21°N, 158°W, just outside the formal area of DOMES. Cruises 45 and 53 of the R/V Charles H. Gilbert and cruises 40 and 46 of the R/V Hugh M. Smith passed through the northern edge of DOMES during the period 1957-1962, collecting planktonic copepods in surface trawls. The same organisms were collected from transects along 174°W between 30°N and 41°S on cruise 55 of the R/V Charles H. Gilbert during 1962, and more recently during the summer of 1969 aboard the Townsend Cromwell along 145°W at 7°N and 12°N in DOMES.

From 1950 to 1960, Scripps Institution of Oceanography, in conjunction with the U.S. Navy Electronic Laboratory, conducted a series of cruises

<u>Station #</u>	<u>Location</u>	<u>Depth</u>	<u>Data Taken Includes</u>
1	11°56', 150°W	11-125m	Surface, intermediate, and deep zooplankton samples were taken.
2	11°N, 150°W	10-260m	
3	10°N, 150°W	6-185m	
4	9°N, 150°W	8-223m	Number/m ³ , volume cc/1000m ³ and adjacent surface volume, cc/1000m ³ was estimated.
5	8°N, 150°W	10-257m	
6	7°N, 149°W	8-223m	
7	6°N, 149°W	8-142m	
8	5°N, 149°W	9-225m	
9	4°34'N, 149°W	9-230m	
10	4°02'N, 149°W	9-233m	
11	3°32'N, 149°W	10m	
12	3°02'N, 149°W	9-172m	
13	2°N, 150°W	9-232m	
14	1°N, 150°W	8-215m	
15	1°N, 149°W	8-215m	

throughout the Pacific Ocean. Cruise tracks from many of these and from subsequent Scripps cruises are available from that institution in computer-generated map format. The cruises listed in Tables 4 and 5 were derived from such computer-generated cruise tracks; they show that the vessels passed through DOMES, but indicate no specific observations made therein. Selected information, including station locations, is available for most post-1967 and some previous cruises through a computerized data-search. Beginning with the SOUTHTOW expedition, in 1972, more comprehensive information regarding Scripps expeditions, and some non-Scripps cruises whose data is digitized at Scripps, was keypunched and may be retrieved from there (Smith et al., 1976). Most recently, Scripps DEEPSONDE, leg 1, January 10-February 2, 1976, crossed the DOMES area between 15°N to 20°N, and 138°W to 147°W.

Typical of cooperative surveys by several U.S. agencies were the two EASTROPAC expeditions of 1955 and 1957. The EASTROPAC area lies east of the DOMES area of interest, but the R/V David Starr Jordan and R/V Thomas Washington ventured into DOMES in the course of collecting physical, chemical and biological data. By now the biological and nutrient chemistry data from participating ships have been summarized in the EASTROPAC atlases, of which 10 volumes have been published to date (Love, 1970-1975).

An era of international cooperation began in 1955 with the NORPAC program in which the U.S., Canada and Japan engaged in extensive physical and biological surveys of the north Pacific, north of the 20°N boundary of DOMES. However, the R/V Umitake Maru passed within the northern border of DOMES during its cruise in 1955. The 1957-1959 International Geophysical Year and the creation of the World Data Center, in which research findings were com-

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Table 4. SCRIPPS Cruises Traversing DOMES, 1952-1966

<u>Expedition</u>	<u>Vessel</u>	<u>Dates</u>
SHELLBACK	<u>Horizon</u>	May-Aug, 1952
CAPRICORN	<u>Spencer Baird</u>	Oct, 1952-Feb, 1953
CAPRICORN	<u>Horizon</u> , legs A,B,C	Sept, 1952-Feb, 1953
TORO	<u>Spencer Baird</u>	May, 1953
TRIPOD	<u>Argo</u> , legs 1,3	Aug-Nov, 1953
CHUBASCO	<u>Spencer Baird</u>	Oct-Dec, 1954
CHUBASCO	<u>Horizon</u>	Nov-Dec, 1954
EASTROPIC	<u>Spencer Baird</u> , <u>Horizon</u>	Oct-Dec, 1955
EQUAPAC	<u>Horizon</u> , <u>Stranger</u>	Aug-Oct, 1956
DOWNWIND	<u>Horizon</u> , legs A,B,D	Oct, 1957-Feb, 1958
DOWNWIND	<u>Spencer Baird</u> , legs A,D	Oct, 1957-Mar, 1958
DOLPHIN "A"	<u>Horizon</u>	May-June, 1958
DOLDRUMS	<u>Stranger</u>	Aug-Sept, 1958
DORADO	<u>Horizon</u>	July-Aug, 1959
HAWAII	<u>Spencer Baird</u>	July-Aug, 1959
TETHYS	<u>Spencer Baird</u> , legs 1,2,3	June-Aug, 1960
MONSOON	<u>Argo</u> , leg 1	Aug-Oct, 1960
	leg 8	Mar-Apr, 1961
ZAPOTEC	<u>Spencer Baird</u>	Oct-Nov, 1960
JAPANYON	<u>Spencer Baird</u> , leg 5	Aug-Sept, 1961
SWANSONG	<u>Argo</u> , legs A,B	Sept-Dec, 1961
RISEPAC	<u>Spencer Baird</u> , legs 1,3	Oct, 1961-Feb, 1962
PROA	<u>Spencer Baird</u> , leg 3	June-Aug, 1962
LUSIAD	<u>Horizon</u> , leg 7	Jan-Feb, 1963
CRISSCROSS	<u>Spencer Baird</u> , leg 1	Feb-Mar, 1963
LUSIAD	<u>Argo</u> , leg 9	July, 1963
AMPHITRITE	<u>Argo</u> , legs 1,3	Dec, 1963-Feb, 1964
DODO	<u>Argo</u> , leg 3	May, 1964
CARROUSEL	<u>Spencer Baird</u> , legs 1,2	June-Aug, 1964
WAHINE	<u>Spencer Baird</u>	Feb-Apr, 1965
SIXPAC	<u>Horizon</u>	Mar-Apr, 1966
ZETES	<u>Argo</u>	June-July, 1966

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Table 5. SCRIPPS Cruises Traversing DOMES, 1967-1975

<u>Expedition</u>	<u>Vessel</u>	<u>Dates</u>
NOVA	<u>Argo</u> , legs 2,3,9	May-Nov, 1967
NOVA	<u>Horizon</u> , leg 6	Sept-Oct, 1967
CIRCE	<u>Argo</u> , leg 2	Mar-Apr, 1968
STYX	<u>Alexander Agassiz</u> , legs 1,2,6,7,8,9	Apr-June, 1968; Aug-Dec, 1968
DEEP SEA DRILLING PROJECT (JOIDES)	<u>Glomar Challenger</u> , legs 5,7,8,16,17,23	Aug, 1968-Dec, 1973
PIQUERO	<u>Thos. Washington</u> , leg 1	Dec, 1967-Jan, 1969
SCAN	<u>Argo</u> , legs 2,3,5,10,11	Apr, 1969-Feb, 1970
SEVENTOW	<u>Thos. Washington</u> , leg 6	June, 1970
ARIES	<u>Thos. Washington</u> , legs 1,4,5	Nov, 1970-June, 1971
ANTIPODE	<u>Melville</u> , leg 7	11 Sept-30 Oct, 1971
SOUTHTOW	<u>Thos. Washington</u> , legs 1, 12	Feb-Mar, 1972; Jan, 1973
CATO	<u>Melville</u> , leg 2	Aug-Sept, 1972
BENTHYFACE	<u>Melville</u> , leg 2	June-July, 1973
GEOSECS	<u>Melville</u> , legs D,K	Oct, 1973-June, 1974
SIQUEIROS	<u>Thos. Washington</u>	June-July, 1974
EURYDICE	<u>Thos. Washington</u> , legs 2,11	Nov, 1974-July, 1975
FRANCIS DRAKE	<u>Melville</u> , legs 1.5	Jan-June, 1975

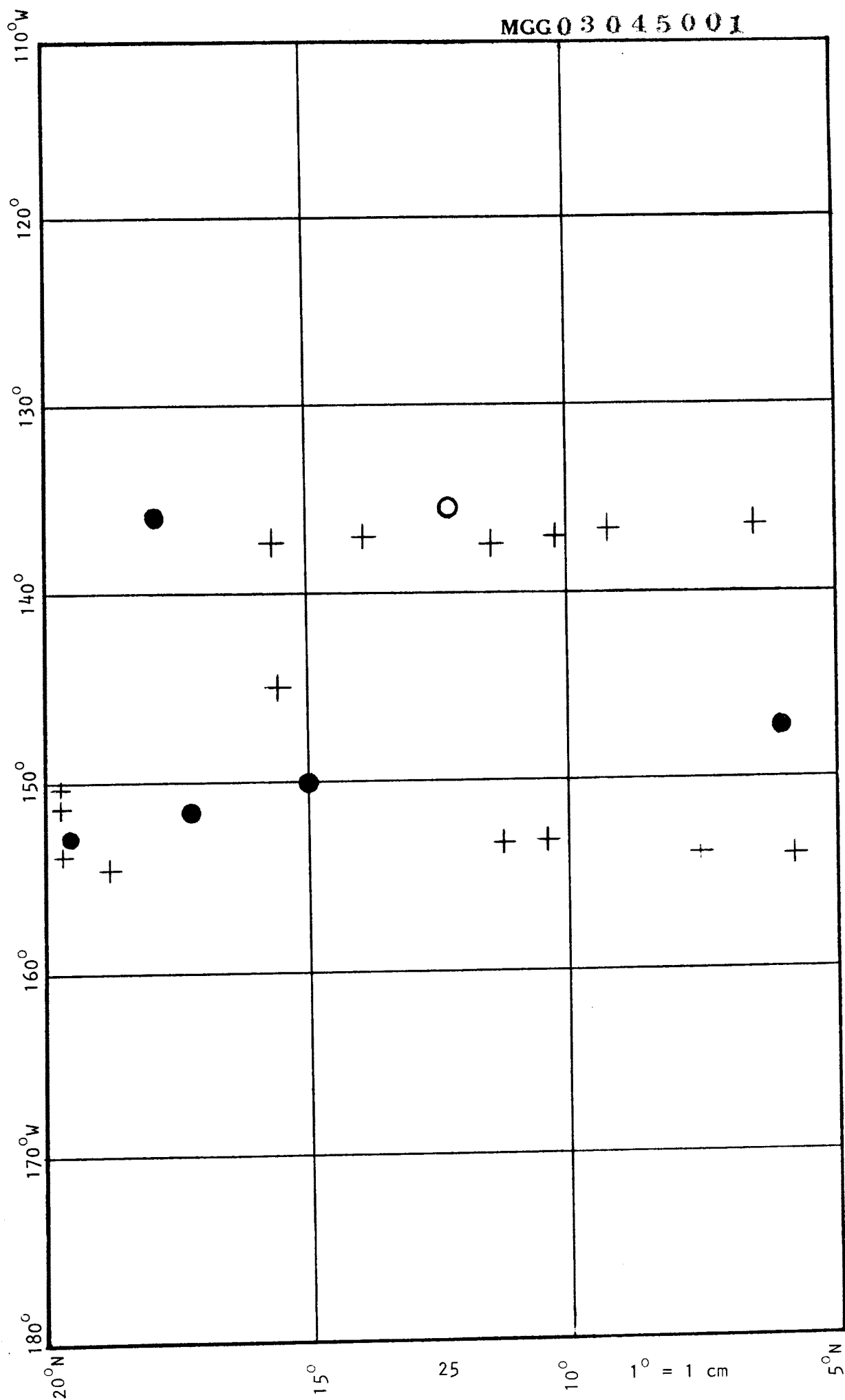
piled, increased by an order of magnitude the quantity of available oceanographic information.

In 1955 the USSR began a series of cruises, which continued through 1959, throughout the world ocean aboard the R/V Vityaz (Vityaz, 1961). These cruises investigated most aspects of oceanography: bottom topography and sediments, water chemistry, hydrogeographic features, currents and circulation, and the taxonomy, distribution and processes of the biota including plankton, benthic organisms, deep-sea fauna, microorganisms, and pelagic species. Data were collected at more than 6000 stations, and vertically from the air-water interface to abyssal depths. Cruises throughout the north-east Pacific included tropical stations, some within or near DOMES.

Because of the immense volume of data collected and the large number of cruises and stations involved, it has not been possible to tabulate the precise location of all stations within DOMES. However, some of this information appears in literature, some of it published in English, subsequent to the Vityaz cruises. For example, Figure 2 presents stations from cruises by the R/V Vityaz, R/V Ob, HMS Challenger and American Albatross in DOMES, during which samples of benthos were taken at various stations. All samples were taken from 2000 m or deeper. Wüst (1964) has charted the tracks of the R/V Vityaz during its 1955-1959 cruises throughout the Pacific, including those for the IGY. Cruise tracks of this period pass directly through the western sector of DOMES along 174°W.

The 34th Vityaz cruise in the early 1960's sampled surface plankton in the Equatorial Current and determined the bacterial biomass in sediments. This cruise traversed DOMES from 140°W to 160°E between 17°N and 8°S. Micro-

Figure 2. Benthic Stations for R/V Vityaz and R/V Ob (+), HMS Challenger (●) and American Albatross (o)



biological investigations were continued during the 43rd Vityaz cruise of 1967-68, which included stations in DOMES. Geological data were also compiled. Subsequently, in 1971, the R/V Akademician Korolyov established microbiological stations in and bordering DOMES along 135°W at 22°N, 16°N, 9°N, and 4°N. The three cruises conducted by TINRO (USSR) in 1965-68, while outside DOMES, collected information contributing to the understanding of the eastern Pacific. These cruises traversed the area from 200 miles off the American coast to 110°W, between 12°N and 53°S, collecting planktonic organisms from the surface to a depth of 100 m in a series of distributional studies.

Beginning in 1964, the Centre O.R.S.T.O.M. of Noumea (New Caledonia) conducted a series of 30 cruises aboard the R/V Coriolis. Investigations included a broad coverage of topics, from phytoplankton to tuna. The zoogeography, ecology, biology, and trophic dynamics of planktonic and micro-nektonic organisms, primarily euphausiids, were of particular interest. The ALIZE expedition (1964-65) passed just south of DOMES along the equator between 86°W and 151°E. The CARIDE expedition (1968-70) traversed the equator between 135°W and 155°E. The purpose of the O.R.S.T.O.M. cruises was to investigate trophic relations and vertical distributions of pelagic fauna in the tropical south Pacific and the equatorial Pacific, and their surveys lie technically outside DOMES; however, findings in equatorial waters are clearly important and applicable to regions of DOMES immediately adjacent.

During the April, 1967, cruise 14 of the R/V Te Vega of the Institute of Marine Sciences, University of Alaska, the region from 13°N to 23°N between 105°W and 111°W, an area of the subtropical eastern Pacific including the northeast corner of DOMES, was sampled from the surface to a depth of 400 m. The uptake of nitrogenous compounds and carbon and the production of chloro-

phyll by phytoplankton were studied, with particular emphasis on the discontinuity layer. General physical and chemical measurements were made.

The B leg of the 1967 Baek-Kyung-Ho cruise, sponsored by Pusan (Korea) Fisheries College, contained 9 stations in DOMES along 157°W at 20°N, 18°N, 16°N, 14°N, 13°N, 11°N and 9°N, and along 156°W at 7°N and 5°N (see Table 6). Three other stations lie equatorward. Plankton displacement volume was sampled from the surface and at intervals to a depth of 600 m (Pusan Fisheries College, Korea, 1968).

As part of the International Biological Programme, Cruise KH-69-4 of the R/V Hakuho Maru, August 12-November 13, 1969, passed through DOMES along 155°W. The cruise had two main interests: productivity and metabolism, and biogeography. Studies included: dissolved organic compounds; distribution, metabolism and isotope ratio of nitrogenous compounds; ecological studies on microorganisms; biochemical studies on photosynthesis and respiration; taxonomy, distribution and production of phytoplankton, seston, zooplankton and micronekton; distribution ecology of fish larvae; studies on individual fish echopatterns and distribution ecology of tuna; and oceanographical observations (Marumo, 1970). Stations 8, 9, 10, and 11 were within the DOMES area, and 12, 13, and 14 are very close. Sampling occurred from the surface and throughout the water column to 5400 m. In addition to the recording of data concerning water masses and current systems, investigations included productivity at lower trophic levels, bacteria, phytoplankton, zooplankton, micronekton, biogeographical distribution, metabolic processes and the structure of the food chain (see Table 7).

The YALOC 69 cruise of the R/V Yaquina of the University of Oregon Department of Oceanography in the eastern equatorial Pacific traversed the northwest corner of DOMES on its return from the Galapagos Islands. Hydro-optical observations, made at various locations along the cruise tracks at approximately

<u>Station #</u>	<u>Location</u>	<u>Depth</u>	<u>Data</u>
B1	20°N, 157°W	0-600m	Displacement volume of plankton (cm ³ /10m ³) converted to g/10m ³
B2	18°N, 157°W	"	"
B4	16°N, 157°W	"	"
B5	14°N, 157°W	"	"
B7	13°N, 157°W	"	"
B9	11°N, 157°W	"	"
B11	9°N, 157°W	"	"
B13	7°N, 156°W	"	"
B15	5°N, 156°W	"	"
B17	3°N, 155°W	"	"
B19	2°N, 155°W	"	"
B21	0°N, 156°W	"	"

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Table 7. Stations in DOMES of the R/V Hakuho Maru, Cruise KH-69-4,
 12 Aug-13 Nov, 1969 under the INTERNATIONAL BIOLOGICAL
 PROGRAMME (IBP)

<u>Station #</u>	<u>Location</u>	<u>Depth</u>	<u>Data Taken Includes</u>
#8	17°N, 155°W	0-4700m	Productivity
#9	13°N, 155°W	0-5400m	lower trophic levels; bacteria,
#10	10°N, 155°W	0-5170m	micronekton,
#11	7°N, 155°W	0-5120m	biogeography;
#12	4°N, 155°W	0-4650m	metabolism; food
#13	2°N, 155°W	0-4820m	chain, water
#14	0°N, 155°W	0-4675m	masses; currents.

13°N, 108°W, and 22°N, 113°W, are applicable to DOMES. Cruise objectives and preliminary results in the areas of marine geology, marine geophysics, physical oceanography and chemical oceanography are reported in the synopsis of the cruise (Byrne, 1969).

During the Hudson 70 cruise sponsored by the Bedford Institute, Atlantic Oceanography Laboratory (Nova Scotia), plankton tows were made at various depths along 150°W from 55°N to 15°S through DOMES. The purpose of this cruise was to establish relationships between physical environment factors such as water mass types, and the distribution of planktonic Foraminifera, particularly protozoan contributors to globigerinoid ooze. The ecology, distribution and processes of planktonic organisms were the principal objects of research by the University of Washington (Seattle) in its series of cruises aboard the R/V Thomas G. Thompson through the oxygen-deficient waters of the eastern tropical north Pacific. Cruise 66, from January 20-March 2, 1966, contained sixteen consecutive stations (numbers 33-48) along 110°W. Chemical analyses of water samples were made; however, the emphasis of the cruise was biochemical, notably the study of the electron transport system of marine bacteria and microplankton, chlorophyll-carotenoids production, and nitrate reductase activity.

The most extensive comprehensive research efforts focused upon a single locality in DOMES were the two Fanning Island Expeditions of January, 1970 (Chave, 1970) and July and August, 1972 (Chave and Kay, 1974), aboard the R/V Mahi. Both of these expeditions were sponsored by the Hawaii Institute of Geophysics, and involved interdisciplinary investigations by biological, chemical, and physical oceanographers. The first expedition consisted of work at sea, including measurements in the South Equatorial Current and Undercurrent, and measurements of the contribution of island detritus to the open sea. The

island-based work was aimed largely at the physical oceanography of the lagoon, biogeographical problems, and primary productivity studies. The second expedition continued these earlier investigations.

The 1972 cruise of the University of Hawaii's R/V Teritu in the oligotrophic photic zone south of the Hawaiian Islands included 2 oceanographic stations: station B in the Kealaikahiki Channel at 20°41'N, 156°55'W, and station C, Kaioli, at 21°22'N, 159°12'W, bordering DOMES. Measurements of radiant energy transmission, plant nutrients and chlorophylls were made from the surface to a depth of 250 m. Vertical distribution, biomass, and taxonomy of phytoplankton, microzooplankton, bacteria and fungi were determined.

RECENT AND ONGOING CRUISES

Some recent cruises through DOMES have emphasized physical, chemical and geological research. One of the most important recent sources of information about the chemistry of the water column in DOMES is GEOSECS Pacific Expedition leg 10 (K), Papeete to San Diego, May 13 to June 10, 1974 (Broecker and Mantyla, 1974). During this final leg of GEOSECS the track was run along approximately 125°W, extending the north-south profile from 20°S to 28°N. Temperature, salinity, O₂, CO₂, alkalinity and nutrients were analyzed in water obtained at the surface and to depths of 4500 m. Stations located within DOMES are presented in Table 8.

The cruises by the R/V Glomar Challenger as part of the Deep Sea Drilling Project (JOIDES) have provided considerable geological and paleogeological data. Chemical composition, lithology, stratigraphy, depositional history, and magnetic anomaly patterns are among the foci of these researches. Legs 5, 7, 9, and 16 contain sites within DOMES (see Table 9). Summary reports of these legs are available from several authors (e.g., McManus, 1969; Hays, 1970;

Table 8. Stations within DOMES of the GEOSECS (R/V Melville) Leg 10(=K)

<u>Station #</u>	<u>Location</u>	<u>Depth</u>	<u>Data</u>
#338	6°N, 123°W	0-4160m	Temperature, salinity, O ₂ , PO ₄ , CO ₂ , Alk.
#339	8°N, 123°W	8-4572m	
#340	10°N, 123°W	0-4521m	
#341	12°N, 123°W	1-4566m	
#342	14°N, 123°W	1-4376m	
#343	16°N, 123°W	13-4194m	
#344	19°N, 122°W	10-4249m	

Table 9. JOIDES, DEEP SEA DRILLING PROJECT, R/V Gloimar Challenger, Sites Drilled within DOMES Area

	<u>Site #</u>	<u>Location</u>	<u>Depth</u>	<u>Data Tabulated Includes:</u>
Leg 5 (1969)	40	19°N, 139°W	5,183m	Penetration (m)
	41	19°N, 140°W	5,339m	Number of cores
	42	13°N, 140°W	4,848m	Recovery
	43	17°N, 151°W	5,405m	Age of core
Leg 7 (1969)	65	4°N, 176°E	4,359m	
	66	2°N, 166°W	5,487m	
Leg 9 (1970)	76	14°N, 145°W	4,597m	
	77	0°N, 133°W	4,290m	
	78	7°N, 127°W	4,377m	
	79	2°N, 121°W	4,573m	
Leg 16 (1971)	159	12°N, 122°W	4,484m	
	160	11°N, 130°W	4,940m	
	161	10°N, 139°W	4,939m	
	162	14°N, 140°W	4,854m	
	163	11°N, 150°W	5,320m	

and Van Andel, 1971), while the full details can be found in the Initial Reports of the Deep Sea Drilling Project, vols. 5, 7, 9, and 16 (McManus et al., 1970; Winterer et al., 1971; Hays et al., 1972; Van Andel et al., 1973).

The other recent cruises have been undertaken as a function of current interest in mining in this region.

The German R/V Valdivia made several series of cruises during 1972-1973 through the vicinity of the Clipperton and Clarion Fracture Zones for the purpose of investigating the origin and distribution of manganese nodules, and mining prospects. After 6 preliminary sea trials, the R/V Valdivia made 4 cruises during 1972 and 4 in 1973, conducting bathymetric and seismic mapping, sampling of nodules and sediment, and continuous ocean-floor scanning with deep-sea TV cameras. The station and cruise pattern was presented as part of the international symposium organized by the Valdivia Manganese Exploration Group and the Hawaiian Institute of Geophysics (Schultz-Westrum, 1973).

Recent and ongoing United States cruises related to mining interests, particularly those funded by the National Science Foundation and by the National Oceanic and Atmospheric Administration, have been described in the introductory section of this literature survey.

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PHYSICAL OCEANOGRAPHY AND METEOROLOGY

METEOROLOGY

INSOLATION

- Solar Radiation
- Absorption of Light

CLOUD COVER

EVAPORATION AND PRECIPITATION

- Evaporation
- Precipitation

EQUATORIAL WIND SYSTEM

AIR-SEA INTERACTION

TROPICAL STORMS

PHYSICAL OCEANOGRAPHY

CURRENTS AND CIRCULATION

- Equatorial Countercurrent
- Equatorial Undercurrent
- North Equatorial Current
- North Equatorial Countercurrent
- California Current

WATER MASSES

VERTICAL DISTRIBUTIONS

- Temperature, Salinity, and Density
- Oxygen and Nutrients

BOTTOM WATER

WAVES

METEOROLOGYINSOLATION

Solar Radiation. Incoming solar radiation is by definition the solar radiation received at the earth's surface (Baker et al., 1966). Absorption of this radiation causes a stratified structure to appear in the ocean. There are three zones--the surface, pycnocline, and deep zones. The absorption that takes place is a function of water clarity that will be discussed. The surface of the ocean receives on the order of $0.25 \text{ cal/cm}^2/\text{min}$, expressed as 0.25 langley's/min (Von Arx, 1962). Lying between 5°N and 20°N , the DOMES area is expected to receive 578 ly/day, radiating to space 502 ly/day with a net gain of 76 ly/day. Cox and Hastenrath (1970) determined the solar radiation at Palmyra and Christmas Islands in 1967 and found a substantially larger surface radiation than was expected from available sources. The wavelengths that are received lie roughly between 0.38μ and 2.5μ and are short wave radiation. Part of this is reflected (surface albedo 8.0% at 10°N , 9.8% at 20°N), and most is absorbed. The received radiation is radiated back to space in the long wave spectrum between 5μ and 20μ and is responsible for the greenhouse effect.

Three major processes are at work on the loss of heat from the ocean surface: (1) radiation of heat back into space, (2) heating of the atmosphere, and (3) evaporation of water from the sea surface (Gross, 1967a). Transportation of the absorbed radiation takes place mainly by air currents (winds) and partly by ocean circulation. The atmosphere transports this heat efficiently by the latent heat in admixed water vapor. In general, the earth is heated in the tropics and subtropics and is cooled by radiating energy, primarily

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from the polar and subpolar regions. Wyrski (1965c) determined the heat exchange for the Pacific Ocean north of 20°S and found that the north Pacific gains heat at a rate of 3×10^{14} cal/sec and maintains equilibrium by heat loss in the Kuroshio region. The rapid vertical transfer of heat in the surface zone creates a nearly isothermal mixed layer zone. The heat is not transported deep enough to warm the cold bottom waters. The deep ocean temperature, therefore, does not change with the season but remains nearly constant. Bathen (1970a) analyzed the processes maintaining the seasonal heat storage in the 0-250 m surface layer in the north Pacific Ocean from observations taken between 10°S and 70°N. He determined, through heat storage calculations, that the greatest amount of heat is stored seasonally in the western tropical Pacific Ocean (477 Kcal/cm) and the least amount in the Bering Sea (77 Kcal/cm). The greatest variation is between 30°N and 40°N, primarily due to changes in the mixed layer depth. Foster (1971) calculated the convection losses from the ocean with the solar radiation influx as a function of time and showed that the development of convection cells was inhibited during the day because of the solar radiation.

Absorption of Light. The upper 100 m of the ocean absorb 99% of the usual radiation. The amount of incident radiation that enters the sea is dependent upon the amount of radiation immediately above the surface and the reflectivity of the surface. The angle of incidence of the radiation largely determines the amount of radiation reflected. When the sky is overcast, the reflectivity averages about 10% regardless of solar altitude. When the sea is rough enough to produce whitecaps the albedo of the water surface increases to about 31% (Malone, 1951). The albedo of the DOMES area between 5°N and 20°N averages 8.7% for the region (Houghton, 1954). Ten meters of water from the

open ocean absorbs between 33% and 80% of blue light, while coast water absorbs all of it (Weyl, 1970). Kalle (1937) showed the presence in sea water of a water-soluble pigment ("yellow substance") whose absorption curve would account for the observed extinction in the blue end of the spectrum. Jerlov (1951) obtained values for the upper 10 m of ocean and coastal waters and found that oceanic water is relatively more transparent to blue than green light. Poole (1945) and Johnson and Liljequist (1938) have studied the amount and quality of light scattered both horizontally and vertically. Results of their studies show that in oceanic water, when the sun is at the zenith, 5%-7% of the blue and violet light (465 and 375 mμ) is scattered upward. Rutkoskaya and Kalemkiy (1974) determined the optical water types in the Pacific Ocean using the Jerlov (1964) optical classification system based on underwater irradiance to determine the amount of radiation received at depth. They found that the incoming radiation is 5-30 Kcal/cm²/yr at 10 m, 2.5-20 at 20 m, 1-10 at 50 m and no more than 1 Kcal/cm²/yr at 100 m of depth. These figures are entirely dependent upon the optical clarity of the water, which varies from location to location.

CLOUD COVER

Equatorial ocean climates are dominated by convective rainfall from dense cumuliform cloud masses associated with the trade winds of the converging gyres of the two hemispheres. The trades on either side of the belt of doldrums (equatorial area) carry a steady procession of cumulus clouds which are variable from day to day (Von Arx, 1962). The sunlight that penetrates to the sea surface in these latitudes is the most intense on earth, warming the seas directly and indirectly to depths approaching 100 m. Water vapor evaporated from the sea is carried upward by trade cumuli to higher levels in the West.

This interaction of wind and sea produces a gradual westward increase in the level of the trade wind inversion in the air (Malkus, 1958) and in the depth of the main sub-equatorial thermocline in the sea.

Malkus and Riehl (1964) studied the development of cloud structures over the mid-tropical Pacific Ocean using aerial cloud photography and synoptic data collection. The results were reduced to cloud maps and measurements. Their findings revealed the important role played by cumulus convection in the conversion of heat energy from latent into sensible form and its transport to great heights. The towering cumulonimbus clouds have been shown to be essential to maintaining the heat and mass budgets and exports from the equatorial trough zones and hurricanes. They established the differential release of latent heat by convective systems that creates the large scale temperature differences in the horizontal which provide pressure force that can drive the air motions against friction. They suggest that the convective clouds are not decorations of the tropical atmosphere but the actual working cylinder of the tropical heat engine. Tropical clouds are the main water supply for over 30% of the earth's surface. The most striking feature of these cumulus clouds is their frequent line up into rows or long streets.

With the advent of satellite photography, cloud observation of the Pacific Ocean came under increasing analysis. This allowed greater synoptic time coverage, establishment of cloud types, and complete coverage of certain types of circulation patterns, e.g. Hadley cells.

Godshall (1968) determined the mean position of the Intertropical Convergence Zone in the Pacific Ocean by wind consistency and resultant vectors. This was compared to the mean total cloud cover based upon TIROS (satellite) data. Alaka (1958), Koteswaram (1958), Reiter (1963), and Flohn (1964) have shown that the weather activity in the equatorial region is closely associated

with the position and strength of strong easterly winds aloft. Further cloud information may be obtained from the U.S. Navy Marine Climatic Atlas of the World, Vol. VII (1965) for cloud types and direction.

Krueger and Gray (1969) and Kilonksy (1974) used satellite observation of clouds to determine the tropical oceanic rainfall in the Pacific equatorial area. Gruber, Herman and Krueger (1971) used the ATS 1 (Advanced Technology Satellite) for the month of November, 1969, to plot the circulation of resultant winds using passive cloud features described by Hubert and Whitney (1971). Bliss (1970) and Hayden (1970) used satellite data for analysis of cloud cover over the Pacific Ocean. Hayden plotted the scale and width of cloud clusters in the tropics with attention on the Intertropical Convergence Zone. Bliss tracked the Easterly Wave depressions.

EVAPORATION AND PRECIPITATION

Evaporation. The amount of evaporation from any part of the ocean surface is controlled by: (1) the amount of insolation, (2) the wind speed, and (3) the relative humidity of the overlying air. Because of the abundant insolation in the tropical and subtropical zones, they experience large amounts of evaporation. Jacobs (1951) has computed the evaporation for the area between 20°N-25°N and arrived at a figure of 148 cm/yr for the Pacific Ocean. Taylor (1932) and others researched the turbulent mixing of the lower layers of the atmosphere and have prepared formulas showing evaporation as a function of moisture concentration and wind movement within the turbulent layer. Evaporation is greatest in winter and least in summer, with the greatest evaporation on the western sides of the ocean. In the north Pacific Ocean between 5°N-20°N and 140°W-175°W this tropical area of high evaporation is considerably better developed and its center varies with the season. In winter the maximum

evaporation within this area is $0.70 \text{ gm cm}^2/\text{day}$. The maximum increases in the spring to 0.72 gm , decreases to 0.62 gm in the summer, and reaches its lowest value (0.56 gm) in the fall. This corresponds to the tropical center of high evaporation that moves in correspondence to the center of the north Pacific high pressure field. Jacobs (1951) computed the total volume of water evaporated annually from the north Pacific and arrived at a figure of $90232.4 \times 10^9 \text{ m}^3$, which equals an evaporation rate of 111.4 cm/yr . The effects of winds on evaporation can be detected. Maximum amounts of evaporation occur in subtropical regions (around 30°N and 30°S) where highly persistent trade winds blow throughout the year. The subtropical zones are areas of clear skies (high insolation) and relatively dry air. The reduced evaporation in equatorial regions (such as DOMES) is due in part to the light and variable winds which give the region its name, the Doldrums. Regional cloudiness also contributes by diminishing the insolation.

Precipitation. Precipitation is greatest in the summer and lowest in the winter for the northern equatorial latitudes and averages around 120 cm/yr for the area in DOMES (Jacobs, 1951). Krueger and Gray (1969) studied the record at Canton Island and found that satellite observations revealed ocean temperature, rainfall, trade wind flow and equivalent potential temperature to be related to three major "centers of action" (standing eddies) in the vicinity of the equator. Probably the major part of the condensation heating necessary for Hadley circulation occurs in these areas. Kilonsky (1974) devised a method for determining open ocean rainfall from satellite observations. Namias (1970) researched the relationship of the wind to the sea surface temperature and the resultant seasonal lags. He found that the amplitude of the sea surface temperature may vary as much as 1°F over the Pacific area between two extreme

years. This will affect rainfall as the heat of evaporation is 47×10^{20} cal or equivalent to 8.14×10^{18} gm of water. Gross (1967a) states this as an equivalency of water 1 m thick that evaporates from the ocean surface. Roden (1963) determined the spectrum of oceanic and meteorological variables for their frequency ranges. He found that air temperature and sea temperature are related, as are salinity and rainfall. These factors will vary directly and inversely with each other with cycles between 0 and 6 cycles/year. Again in 1973, Roden investigated the thermocline structure, fronts, and sea-air energy exchange for the trade wind region east of Hawaii. His findings showed that the southern front is present in the zone of strongest net evaporation between latitudes 11°N and 12°N , and is characterized by a salinity gradient of $1^{\circ}/_{\text{oo}}/36$ km and a strong baroclinity in the upper 50 meters (Roden, 1974). The northern or subtropical front is encountered between 31°N and 33°N and is in the region of the confluence of the California Current. Evans (1971) used sea surface temperature and salinity from ships' tracks in the eastern north Pacific to characterize regions of surface water over a broad area.

Bjerknes (1969) has shown that the maximum of the sea surface temperature in the eastern and central Pacific occurs as a result of the weakening of the trade winds with an inherent weakening of the equatorial upwelling. Moiseyev (1970) through thermal soundings found that lenses of different density, temperature, and salinity were produced in converging meridional flows out of the Intertropical Convergence Zone which directly influences the whole equatorial area. This is the converging area for currents from both the North Pacific and South Pacific Gyre with the similar configuration with atmospheric currents produced in the atmosphere above the sea surface.

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EQUATORIAL WIND SYSTEM

The motions of the wind system are produced in the same manner as that of the oceans--through horizontal variations in density and pressure, and coriolis acceleration. Studies of atmospheric structure reveal the circulation of the atmosphere at the tropical equatorial and subtropical equatorial as being produced by the rise of warm water vapor-laden air. Most of this heat is transported in the form of latent heat rather than sensible heat. Upon reaching the upper atmosphere, the air mass travels northward and then generally sinks around 30°N . This motion of air is known as a Hadley cell. The motion of the atmosphere in the DOMES area is provided by the trade winds. These steady winds show a high degree of directional persistence in the area from 5°N to 25°N with a wind velocity of 500-750 cm/sec (Weyl, 1970). The response of the ocean to these environmental changes occurs in two distinct modes: (1) the barotropic mode, in which the pressure distribution of the sea is altered, and (2) the slower baroclinic mode, which involves the redistribution of density. The ocean is unable to keep in step with these alterations, so it maintains an almost constant equilibrium. Wyrcki and Myers (1975a, 1975b) researched the coupling of current fluctuation in response to wind systems. They found these currents were responsible by advection for redistribution of the heat input of the ocean. Consequently, they play a major role in the coupling of the entire ocean-atmosphere system in large time and space scales. The coupling was observed from oceanic island stations in and out of the DOMES area. The North Equatorial Current and the Countercurrent fluctuate synchronously and in opposition to the currents to the south. The fluctuations of the currents are related to the trade winds and are more strongly influenced by the position of the trade winds rather than their strength. When the northeast trades are strong and in a southerly position

during the first half of the year, both the North Equatorial Current and the Countercurrent are weak; when the trades are weaker and in a more northerly position during the second half of the year, both currents are strong. Meyers (1975) studied the seasonal variation in transport of the North Pacific Equatorial Current relative to the wind field and found that the current varies seasonably from a minimum in spring to a maximum in the fall (Seckel, 1975; Wyrski, 1974a, 1974b). However, in contrast, the northeast trade wind system is most vigorous and extensive in spring and weakest in fall (Crowe, 1951). Meyers (1975) solved this problem using the model by Yoshida (1955) and Fedorov (1961) to analyze the effect of wind stress curl on thermal structure. The Intertropical Convergence Zone (ITCZ) greatly influences the north atmospheric and oceanic circulation, even though it lies out of the DOMES area. It is generally strongest in the spring and weak in the fall. Godshall (1968) and Snitkovsky (1972) have studied the ITCZ. Godshall studied the cloud cover and found the mean intensity of the cloud cover in January and August to be somewhat out-of-phase with the ITCZ. Snitkovsky studied the wind, pressure, cloud and precipitation fields that were present.

AIR-SEA INTERACTION

Weyl (1970) states that the transfer of heat from the ocean to the air takes place by conduction of heat through the sea surface. If the water is warmer than the air, the air in contact with the sea is warmed until the temperatures are equal. In addition to a transfer of sensible heat (the portion of energy exchanged between ocean and atmosphere which is utilized in changing the temperature of the medium into which it penetrates to warm the air), there is a transfer of water vapor. Only if the air has the same temperature as the water and is saturated with water vapor are the two in equilibrium. Latent

heat (the heat released or absorbed per unit mass by a system in a reversible isobaric isothermal change of phase) is transferred to the air, to be released in the atmosphere when the moisture condenses and returns as rain or snow. As the heat capacity of air is roughly independent of temperature, the sensible heat required to equalize a given temperature difference for a unit mass of air is independent of temperature. The moisture content at saturation increases rapidly with air temperature, and as a result the latent heat requirement increases as the air becomes warm. The high heat of vaporization of water and the rapid increase in the saturation value of water vapor content with temperature limit the temperature to which air over the ocean can be heated. Bathen (1970a, 1970b) analyzed the processes maintaining the seasonal heat storage in the 0-250 m surface layer in the north Pacific Ocean. He found that advection (estimated from the local change in heat storage, the contribution of mixing and the net surface heat exchange) was of an importance equal to or greater than that of the net surface exchange in determining the local thermal structure. His findings for the DOMES area showed there to be a high of between 500-340 Kcal/cm² in the 0-250 m surface layer.

TROPICAL STORMS

The intensity, seasonality, and trajectories of several recent tropical storms and extreme weather conditions in the northeastern Pacific have been described (Baum, 1973, 1975; Baum and Rasch, 1975; Dickson, 1972). Further vector mean charts of north Pacific tropical cyclones have been constructed by Crutcher (1973). In some studies of tropical storms in the northeastern Pacific, aircraft reconnaissance and satellite observations have been made (Parmenter, 1970; Pierson et al., 1973; Upton, 1973).

In a series of papers, Crutcher and Hoxit (1973a, 1973b, 1973c) have compiled strike probabilities for north Pacific tropical cyclones and stratified their data into seasons and geographical areas. Further, studies of the factors affecting tropical storm occurrence (DeAngelis, 1975; Dickson, 1975; Harding and Larson, 1975) and simulation modeling of cyclone tracks (Mauck, 1975) have afforded better understanding and prediction of tropical storms.

PHYSICAL OCEANOGRAPHY

CURRENTS AND CIRCULATION

The circulation in the eastern equatorial Pacific Ocean is dominated by the eastern and equatorial parts of the subtropical anticyclonic gyres of the north and south Pacific Ocean as shown in the monthly charts of surface currents drawn by Wyrтки (1965a). In the north Pacific Ocean these consist of the California Current and the North Equatorial Current. Between this and the Southern Gyre the Equatorial Countercurrent is developed as long as the intertropical convergence is sufficiently north of the equator. The general westward flow in the North and South Equatorial Currents is opposed by two currents flowing east--the Equatorial Countercurrent between 4°N and 10°N, and the Equatorial Undercurrent flowing at the equator below and opposite the South Equatorial Current. On approaching the coast of America, the eastward-flowing water masses are recirculated into the flow to the west (Wyrтки, 1967a). These currents are the result of the response of the ocean and atmosphere to the flow of energy from the tropics and subtropics to the subpolar regions. The basic pattern of these ocean currents is a nearly closed system known as a gyre. The one influencing the DOMES area is the North Subtropical Gyre situated at approximately 30°N. Each gyre consists of four currents.

The northern and southern limits of each gyre are marked by nearly east-west currents, one flowing almost due east, another flowing almost due west. These open ocean currents are joined by boundary currents which flow nearly parallel to the continental margins. The open ocean currents such as the North Pacific Current or the North and South Equatorial Currents flow between three and six km per day and usually extend at least 100 to 200 m below the surface.

Tsuchiya (1968) found that the currents were relatively shallow and used the 500 decibar (~ 500 m) level to estimate the geostrophic current flow in the upper layers of the intertropical region. Knauss (1961) estimated the volume flow of the Pacific Equatorial Countercurrent at $60 \times 10^6 \text{ m}^3/\text{sec}$ across a width of 300-500 km. Wyrski and Kendall (1967) found the principal transport of the countercurrent to be located above the thermocline and calculated the flow at $40 \times 10^6 \text{ m}^3/\text{sec}$, but found that the current weakens considerably in the period from March to June.

Subsidiary currents have been found. Tsuchiya (1972) found a subsurface equatorial countercurrent just south of the North Equatorial Countercurrent. He found this layer between 3°N and 6°N , and it persisted between 119°W and 98°W at 30 cm/sec at 100-200 m. Its width was 110-160 km and it had an average transport eastward of $32 \text{ km}^3/\text{hr}$ ($9 \times 10^6 \text{ m}^3/\text{sec}$). White (1974) determined the current between 2° - 5°N and 10°N along 122°W - 5°W latitude using the "thermocline" equation of Wyrski and Kendall (1967) and the two-layer thermocline model of Miropol'skiy (1970) to calculate the depth of the thermocline.

Knauss (1963) presents four general ways in which knowledge of ocean currents has been obtained: (1) ship drift components, derived from ship movements with allowances for wind, such as those presented by Stidd (1974a, 1974b); (2) distribution of properties, in that the circulation is inferred from the gradient of certain properties such as temperature and salinity, oxygen con-

tent, phosphate content, and radioactive materials; (3) geostrophic currents; (4) velocity measurements. The most recent circulation studies of the eastern tropical North Pacific are by Halpern (1976).

Equatorial Countercurrent. The Equatorial Countercurrent flows from west to east across the entire Pacific Ocean a few degrees north of the equator. It is relatively narrow, only 300 to 700 km wide, and separates the broader westward flowing North and South Equatorial Currents. As such, it acts as the boundary between the great anticyclonic gyres of the north and south Pacific Ocean. The speed, width and transports of this current vary considerably with the season, as well as over short periods, as shown by Austin, et al. (1956). The main flow of this current is concentrated in a shallow surface layer. Velocities decrease rapidly within the thermocline.

Transports of the Countercurrent have been computed for 79 hydrographic sections by Kendall (1966, 1971) and Wyrtki and Kendall (1967). Using a two-layer model to estimate transports from bathythermograph sections, transports could be estimated for 50 additional locations. According to these calculations, the average transports of the Countercurrent decrease almost linearly from $40 \times 10^{12} \text{ cm}^3/\text{sec}$ in the western part of the Pacific Ocean to less than $10 \times 10^{12} \text{ cm}^3/\text{sec}$ off the coast of Central America. East of 140°W , transports are usually less than $20 \times 10^{12} \text{ cm}^3/\text{sec}$ and tend to decrease to the east. During the period from July to December the Countercurrent is well developed and extends right to the coast of Central America, while from March to May it is usually absent or markedly weaker. This agrees with the monthly charts of surface currents by Wyrtki (1965a). At 150°W the Countercurrent transports chiefly warm water ($>25^\circ\text{C}$) with salinities of less than 35‰ , according to Montgomery and Stroup (1962). All this water is surface water of relatively low density. The contribution of water of lower temperatures to the total transports of the current is rather

small. As the Countercurrent progresses to the east its salinities decrease due to the great excess of rainfall over evaporation in the area of the Inter-tropical Convergence Zone.

Equatorial Undercurrent. The Pacific Equatorial Undercurrent, first reported by Cromwell et al. (1954), has been comprehensively described by Knauss (1960, 1963). This current flowing east in depths between 50 m and 300 m transports about $34 \times 10^{12} \text{ cm}^3/\text{sec}$ at 150°W according to Montgomery and Stroup (1962), and $40 \times 10^{12} \text{ cm}^3/\text{sec}$ at 140°W according to Knauss (1960). Although minor short-term variations in the zonal velocity have been observed by Knauss (1960), the hydrodynamics of the system make it unlikely that the current is subject to appreciable seasonal variation. Where the current is fully developed it draws water from both sides of the equator towards its core, as has been shown by Charney (1960) on the basis of theoretical considerations. This water comes out of the discontinuity layer on both sides of the current, is subject to strong mixing processes and is discharged upwards and downwards, or increases the eastward transport of the current. The Undercurrent discharges all of its water to the north or south and contributes also to upwelling. At 150°W the Undercurrent chiefly transports water with temperatures between 12°C and 20°C and with salinities near 35‰ , as shown by Montgomery and Stroup (1962). Williams and Gibson (1974) reported on direct measurements of turbulence in the Pacific Equatorial Undercurrent, and Jones (1969) on direct measurements of speed and direction.

North Equatorial Current. The North Equatorial Current is formed by water from the California Current, by water from the Countercurrent, a part of which turns north and west around the Costa Rica Dome (Wyrtki, 1964), and by water ascending in the eastern tropical Pacific Ocean. The California Current contributes about

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$12 \times 10^{12} \text{ cm}^3/\text{sec}$, the Countercurrent about $10 \times 10^{12} \text{ cm}^3/\text{sec}$, with both current volumes varying by season.

The North Pacific Equatorial Current has been shown to be subject to change. Seckel (1975) showed the seasonal change varied from 5 cm/sec during spring to 15 cm/sec during the fall. He placed the center of the current near 15°N or 16°N , with its northern boundary between 20°N and 23°N .

North Equatorial Countercurrent. Tsuchiya (1968) revealed a continuous countercurrent almost all across the ocean. The northern and southern boundaries are well-defined for the upper three layers. Below the sea surface the northern boundary is clearly defined west of 120°W by the water characteristics, but the southern boundary is defined only between 118°W and 150°W . The vertical distribution of temperature in the region of the thermocline is intense, with a great range; however, the vertical salinity change is small.

California Current. The California Current is a very weak and slow southward flow, spread over a distance of more than 1000 km from the coast. Based on observations during the NORPAC Expedition, Wooster and Reid (1963) calculated transports of about $12 \times 10^{12} \text{ cm}^3/\text{sec}$ to the south. This flow is strongest the first half of the year ($2-8 \times 10^{12} \text{ cm}^3/\text{sec}$) and much weaker during the second half ($1-4 \times 10^{12} \text{ cm}^3/\text{sec}$) (Wyrтки, 1967a). Below the southward flow in the surface layer, a northward flow is developed and carries between $1-4 \times 10^{12} \text{ cm}^3/\text{sec}$. The water carried south across 30°N in the surface layer of the California Current is cool ($15^\circ-20^\circ\text{C}$) and of low salinity (about 33.5‰). The lowest temperatures are found in coastal upwellings.

The water of the California Current is of moderate temperature and low salinity due to its origin in the temperate climatic zone of the north Pacific

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Ocean. During its flow to the south, salinity as well as temperature increases downstream (Reid et al., 1958).

Tsuchiya (1975) used data from the EASTROPAC expedition in 1967-1968 and found two narrow, stable eastward countercurrents at approximately symmetrical positions about the equator in the subthermocline layers of the eastern equatorial Pacific Ocean. They persist throughout the year without apparent seasonal variation in intensity and position. The northern of the two lies at 3°N-6°N with an average width of 150 km and extends at least as far as 95°W. The depth at which the maximum eastward speed occurs varies from 100 m to 200 m at 119°W and from 30 m to 100 m at 95°W. The maximum geostrophic speed and the average geostrophic transport (over 500 db) are estimated to be 27 cm/sec and 30 km³/hr.

Geostrophic currents are steady currents in which the coriolis effect is balanced by horizontal pressure gradients, which can be calculated from measurements of temperature and salinity. Seckel (1968), describing the Trade-Wind Zone Oceanography Pilot Study, concluded that the boundaries of the major water masses that lie within this zone are ultimately related to the field of geostrophic flow. Wyrli (1974c) calculated the geostrophic flow at the surface of the Pacific Ocean relative to the 500 and 1000 decibar levels. Sverdrup et al. (1942) and Reid (1948) have shown that the torque of the wind stress is a possible mechanism for the maintenance of the North Equatorial Countercurrent.

Winds can induce vertical movements in sea water as well. Both upward movements (upwelling) and downward movements (sinking) can be induced in the open ocean. Along the equator the winds induce upwelling because of the change in the direction of the coriolis acceleration at the equator. The westward-flowing, wind-driven surface currents near the equator are deflected northward on the north side of the equator and southward on the south side. The surface water moving to both sides of the equator is replaced by the upwelling of deep water. Further current information may be obtained from atlases of the U.S.

Navy Hydrographic Office (1947, 1950a, 1950b), and Barkley (1968), and data reports (Guthrie et al., 1974).

In deep ocean circulation, the waters move sluggishly. These deep currents are almost completely separated from wind-driven circulation by the pycnocline and are driven primarily by differences in sea water density. Temperature and salinity are the primary factors controlling sea water density. Hence, the deep ocean circulation is frequently called thermohaline circulation. Unlike the surface currents, the movements of bottom waters are strongly influenced by bottom topography. Johnson (1972a) observed current velocities less than 10 cm/sec east to northeastward along the Clipperton fracture zone which led to the conclusion that the fracture zone may serve as a major barrier to the abyssal circulation. Abyssal circulation has been studied by Wooster and Volkman (1960), Reid et al. (1968), and Gordon and Gerard (1971). Direct current measurements were obtained by Reid (1969), Johnson and Johnson (1969, 1970), and Gordon and Gerard (1971).

WATER MASSES

Wyrtki (1967b) has defined water masses as bodies of water extending horizontally and vertically which have specific characteristics with respect to temperature and salinity. At the sea surface, water masses are formed as a result of the climatic conditions prevailing in different regions of the ocean. The causes of formation of water masses are heating, cooling, precipitation, evaporation, ice formation and melting. The layer in which the original property of a water mass is best preserved is called the core layer and represents a stable minimum or maximum of the conditions prevailing in it. Surface water masses extend over a wide range of climatic types and consequently several water masses are found with characteristics corresponding to the different

climatic regions. There are three basically different types of water involved in DOMES: (1) tropical surface water of high temperature and low salinity, (2) subtropical surface water of high salinity which is generally warm but variable in temperature, and (3) surface water of the California and Peru Currents, which is cool and of low salinity, and originates in higher latitudes. Tropical surface water is found in regions where sea surface temperature is high and its seasonal variation is small, and where salinity is low due to an excess of rainfall over evaporation. In the eastern tropical Pacific Ocean this water can be identified as being present in the area where the surface temperature is always higher than 25°C . Salinity is usually less than $34^{\circ}/_{\text{oo}}$ due to an excess of rainfall over evaporation greater than 50 cm/yr (Dietrich, 1957). The northern boundary of the tropical surface water can be identified approximately with the 25°C isotherm which lies 15°N and fluctuates during the year by about 5° of latitude. The salinity varies from $34^{\circ}/_{\text{oo}}$ to $30^{\circ}/_{\text{oo}}$ at the end of the rainy season (Bennett, 1963). West of 130°W and north of 4°N , temperature and oxygen content in the salinity maximum are again much higher. The subtropical subsurface water of the north Pacific Ocean originates near the center of the North Pacific Anticyclonic Gyre. Subtropical salinity maxima with salinities of more than $36.5^{\circ}/_{\text{oo}}$ can be seen near 20°S and 25°N . From both these centers a subsurface salinity maxima spreads equatorwards. In the North Pacific it is carried east in the lower layer of the Countercurrent and is marked by tongues of high salinity ($>34.8^{\circ}/_{\text{oo}}$), higher temperature ($>18^{\circ}\text{C}$) and higher oxygen content ($>3.0\text{ ml/l}$). This tongue extends to about 115°W (Wyrski, 1967a). The depth of the salinity maximum resembles the general features of the topography of the thermocline as shown by Wyrski (1965b). North of the equator the salinity maximum is situated below the center of the permanent thermocline. Reid (1965) discussed the two tongues of low salinity,

low temperature water that extend from the sea surface in high latitudes to subsurface depths in low latitudes. This water mass extends for the length of the equator and over a latitude range of 30° in the east to 10° in the west. Reid (1973) continued his work on the intermediate-depth waters, plotting the salinity minimum along the eastern boundary currents and their turn westward with the trade wind drift. He found that eddy currents and vertical mixing eventually eliminate the shallow minimum as they extend equatorward. Wong (1972), using potential temperature and dissolved oxygen, has inferred two deep zonal water masses at approximately 5°S and 10°N from 170°W to 130°W at a depth of 4-5 km.

VERTICAL DISTRIBUTIONS

Temperature, Salinity, and Density. Cromwell (1954) obtained data from the Hugh M. Smith cruises and from the Carnegie cruises (Fleming et al., 1945) in the transequatorial waters of the Pacific on the existing bounds of the Equatorial Countercurrent at 158°W - 166°W and 3.5°N - 9°N . Measurements were taken in the core layer from temperature, salinity and dissolved oxygen. Cromwell (1958) and Wooster and Cromwell (1958) studied the area of the eastern tropical Pacific to record oceanographic data. Similarly, Forrester (1964) studied the equatorial region between 97°W and 178°E and 2°S to 2°N for the thermocline spread of the Equatorial Undercurrent and used the 15°C , 20°C , and 25°C isotherms to plot the current. Wyrski (1965c, 1965d, 1966) used average sea surface temperature to determine the amplitude of the annual and semiannual temperatures north of 20°S by 2° squares. The data were then compiled into five charts, and the heat exchange of the surface of the ocean was calculated. The data indicated that the north Pacific Ocean has a net gain of heat at the rate of 3×10^{14} cal/sec, which is probably one of the reasons no deep water is formed

in the ocean basin. The value balance of the north Pacific Ocean is maintained by an outflow of $8 \times 10^6 \text{ m}^3/\text{sec}$ which takes place partly through the Indonesian waters and partly in the eastern tropical Pacific from the Countercurrent and the South Equatorial Current. The North Pacific gains heat chiefly along its eastern side and south of 25°N ; the main heat loss takes place in the Kuroshio region.

Bernstein (1974) confirmed the existence of large mesoscale surface eddies east of Hawaii using subsurface temperatures and found these large eddies (>500 km in wavelength) at depths of 200 m with a flow of 1.5 ± 0.7 cm/sec. McKean and Ewart (1974) used a self-propelled instrument carrier to record subsurface water temperatures off Hawaii between 500 m and 2500 m in depth. The salinity in the DOMES area varies from $35^\circ/\text{oo}$ to $33.5^\circ/\text{oo}$ (Roden, 1963; Reid, 1969; Evans, 1971). Salinity changes have a pronounced effect on sea water density. A change in salinity of $1^\circ/\text{oo}$ causes a greater density change than does a temperature change of 1°C . The pycnocline, in areas of large rainfall such as the Intertropical Convergence Zone, frequently coincides with the halocline. It has been shown that these processes are directly linked to the development of the oceanic currents through differences in salinity and density. As the currents flow west and eastward in the north Pacific Ocean, heat is either absorbed through insolation or released through evaporation, raising or lowering the surface temperature of the currents. Eddy currents and advection considerably alter the simple latitudinal pattern. Sverdrup et al. (1942) showed that the surface salinity varies with latitude in conjunction with surface temperature and the atmospheric air currents. The salinity is at a minimum near the equator and reaches a maximum at about 20°N and 20°S . Values for DOMES may be obtained from Robinson and Bauer (1976). This is a function of evaporation losses, with the salinity decreasing as cooler latitudes are approached.

Separating the sun-warmed surface isotherm from the cold deep water zone is the thermocline where the temperature changes greatly with depth. Where the thermocline exists, it is the main indication of the pycnocline. The thermocline for the DOMES area is relatively shallow. Montgomery and Stroup (1962) found few thermoclines greater than 180 m in depth at 150°W, as did Reid (1965), researching the waters along 160°W longitude. As the thermocline, pycnocline, and halocline are closely related, it is to be expected that they will be found close to the same depth in most areas. Large changes of salinity with depth form a halocline. These changes are directly related to evaporation of water from the ocean surface, by precipitation, and by river discharge from the continents (Sverdrup et al., 1942).

Oxygen and Nutrients. Oxygen can be added to the sea by absorption of air into the upper surface layers and, in a layer strictly limited by the depth of light penetration, by photosynthesis. At the surface, oxygen (O_2) can be lost from the sea by exchanges with the atmosphere, but at all depths it is consumed by the respiration of plants and animals including the decomposition of organic materials by bacteria and the reduction by various chemical processes (Richards, 1957). The solubility of O_2 in sea water decreases with increased temperature and salt content, the difference between the partial pressure of O_2 in sea water and in air determining the direction of the exchange with the atmosphere. In regions where there is extensive photosynthetic production of O_2 , excess gas will tend to escape into the atmosphere and, in regions where upwelling brings unsaturated water to the surface, O_2 will tend to be absorbed by water (Fleming and Revelle, 1939). Rossby (1936) used the O_2 -salinity correlation as a quasi-conservative property of the Gulf

Stream; he found it more useful than the salinity-temperature correlation in studying exchanges between the stream and surrounding waters.

The outstanding feature of the Pacific Ocean is the large wedge-shaped area of very low O_2 extending at intermediate depths westward from the Gulf of Panama, where it was first observed by Schmidt (1925). Lowest concentrations (<0.25 ml/l) are found at about $15^\circ N$ and $10^\circ S$ with somewhat higher concentrations at corresponding depths (down to around 1000 m) in the intervening zone. Reid (1965) observed that where the layers that lie at intermediate depths at low latitudes intersect the sea surface, the concentration of dissolved O_2 is about the saturation concentration for the corresponding temperature and salinity. Values as high as 7 ml/l were observed with average values as high as 5 ml/l for tongues of intermediate water that penetrate into the equatorial region.

Knauss (1963) noted that because the thermocline is a zone of high stability, reduced mixing takes place across it. The water in the mixed layer above the thermocline is high in oxygen and low in phosphate and silicate. Below the thermocline the water is low in oxygen and rich in phosphate and silicate. Wyrski (1967a) found that as the water is discharged by the Equatorial Undercurrent, the oxygen content decreases to values of less than 0.25 ml/l. While the subtropical subsurface water of the north Pacific Ocean has an oxygen content of greater than 3.0 ml/l and runs north of 4° and extends to $115^\circ W$, Tsuchiya (1968, 1975) charted oxygen minima for the various current systems of the equatorial area. References to oxygen and nutrients may be obtained from the EASTROPAC atlases (Love, 1970-1975).

Nutrient concentration in general is characterized by four layers: (1) a surface layer in which concentrations are low and relatively uniform with depth; (2) a layer in which the concentration increases rapidly with depth;

(3) a layer of maximum concentration that is usually located somewhere between 500 and 1600 m; and (4) a thick bottom layer in which there is relatively little change of phosphate and nutrients with depth, although silicate may increase considerably below 2000 m.

Upwelling may at certain times replace impoverished coastal water by nutrient-rich deep water. This is important, for example, along the California coast, Peruvian coast, and West African coast. Phosphate-phosphorus ($\text{PO}_4\text{-P}$) cycles are found throughout the ocean in various stages of inorganic and organic compounds (Reid, 1962). The inorganic phosphate-phosphorus concentrations are measured by chemical means and are a standard test for the richness of various bodies of water. Silicon and the silicates are themselves not nutritive but are required for the construction of skeletal components of diatoms and radialorians.

Distribution of nutrients can be considered under the heading of surface values, the transition zone (where the phosphates increase with depth) and lower zones with higher nutrient concentration. The concentration of nutrients in these zones and the depths of the zones vary from region to region, and the differences are intimately bound up with the current systems of the oceans. Between 10°N and 40°N in mid-ocean, the phosphate content at the sea surface is extremely low, nowhere exceeding 0.15 mg at P/m^3 and commonly half this quantity (Barnes, 1957). Montgomery and Stroup (1962) researched the phosphate-phosphorus levels along the 150° meridian and obtained values from 0.4 to $2.8 \text{ } \mu\text{g/l}$. Reid (1962) considered the $\text{PO}_4\text{-P}$ content of the Pacific Ocean to be subject to influence by two high-latitude cyclonic gyres, two subtropical anticyclonic gyres, and a series of subequatorial zonal lows in alternate directions. The $\text{PO}_4\text{-P}$ at the surface is related to the surface divergence and is high in the cyclones, low in the anticyclones, and high in regions of coastal and equator-

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ial upwelling. The PO_4-P at 100 m is related to the depth of the pycnocline and is also high in the cyclones and low in the anticyclones, and high at the equator and poleward edges of the equatorial countercurrents.

BOTTOM WATER

Classic studies of bottom temperature and bottom currents in the Pacific were made by Wüst (1929, 1937, 1939). Subsurface water masses are formed and maintained by the increase in density of the water and the induced thermohaline convection. In the ocean, the processes which are controlled by thermohaline circulation are: the formation and the sinking of bottom and deep water in the polar regions, the formation of the main thermocline which separates the warm water sphere and the cold water sphere, and the sinking of high salinity waters in the subtropics. Kuo and Veronis (1970) and Reid and Lynn (1971) state that most of the Antarctic Bottom Water is formed in the Weddell Sea near Antarctica where the formation of ice in the winter and probable evaporation increase the salinity of the water to 34.67‰ at temperatures of -1.9°C , thus forming the densest water in the Southern Hemisphere. This water forms at the rate of $10 \times 10^{12} \text{ cm}^3/\text{sec}$, sinks along the slope of Antarctica into the deep sea and spreads into all oceans. The spread into the Pacific basin occurs by eastward flow around Antarctica and then northward flow east of New Zealand. The potential temperature of the bottom water has been increased to about $+1.0^\circ\text{C}$ by mixing with the overlying water masses.

The deeper water of the Pacific Ocean is a mixture of Antarctic Bottom Water and North Atlantic Deep Water, which has passed through the South Atlantic and South Indian Oceans and enters the Pacific Ocean south of New Zealand. This water is very homogeneous with respect to salinity (34.68‰) and fills the entire Pacific Ocean below about 2500 m. East of New Zealand and Fiji

this water spreads north, enters the Central Pacific basin toward Japan and turns east in an anticyclonic circulation (Wooster and Volkmann, 1960). Antarctic intermediate water, formed at the surface of the South Pacific in high latitudes, spreads north between 600 m and 1200 m in depth. Its core layer has a temperature of about 5°C and is characterized by a salinity minimum and by high O_2 content. Panfilova (1967) investigated the bottom water temperature and salinity for the equatorial area.

Knauss (1962) inferred the flow of the deep Pacific water from the distribution of temperature, salinity and radioactive carbon. His conclusion was that all water below 2500 m in the Pacific was from a single source in the south and flowed predominantly northward. The effect of heat flow from the earth's interior was deemed by Knauss (1962) and by Von Herzen and Anderson (1973) to be of less importance than a modification by upper water of the characteristics of bottom water. He estimated the northward speed and transport of this flow and derived values of 0.05 to 0.1 cm/sec and 15 to 25×10^{12} cm³/sec. Reed (1969) found from SEAMAP data that water from the south appeared to spread into the northern region by way of a western route rather than directly from the south through the central region. Reid and Lynn (1971) traced the waters formed in the Norwegian-Greenland and Weddell seas to the abyssal Pacific and Indian Oceans by examining distributions of temperature and salinity along a stratum defined by density parameters. Their research extended to depths of 3500 m in the central oceans and below 4000 m in the north Pacific. Edmond et al. (1971), using high-precision temperature profiles and hydrographic data from the north Pacific, showed the existence of a narrow eastward bottom current. This current flows along the southern flanks of the Mid-Pacific mountains through a deep passage 10 km wide south of Horizon Guyot and on around the southeastern end of the Hawaiian chain. Mantyla (1975) presents some evidence for the modification of the

potential temperature of the Bottom Water by vertical mixing and geothermal heating into Pacific Deep Water which must return southward above the Bottom Water layer. The potential density of bottom water is greater than 1.0278 g/cm^3 and therefore has been recognized as coming from the south. As the bottom water spreads northward into the Pacific basins, it becomes warmer through the processes of mixing with warmer shallower water and bottom heat flow. Chung (1971, 1975) continued his study of bottom waters and the areal extent of the benthic front. This is a spatially-continuous sharp vertical gradient separating the cold Bottom Water and the warmer Deep Water in the Pacific. The extent of the benthic front indicates spreading of the Bottom Water from the antarctic circumpolar region into the Pacific. It is found that the Bottom Water spreads as far north as 20°N in recognizable temperature form.

WAVES

Ordinary waves are composed of two varieties: (1) locally wind-generated waves, with short periods, unsymmetrical slopes and steep or white-capped crests, depending on wind speed and fetch, and (2) waves which have passed beyond the area of their formation and are called swells, with relatively symmetrical shapes and relatively long periods.

The waves will vary under atmospheric conditions, and the sea state may consist of a mixture of waves from different directions with different heights and periods. The Beaufort Scale for wind force was introduced in 1806 by Admiral Sir Francis Beaufort as a purely practical approach that recognizes the interdependence of wind force and sea state. Within the past decade a new approach has been developed in which the wave spectrum, a concept introduced by G.E.R. Deacon, N.F. Barber, M.S. Longuet-Higgins and F. Ursell of the National Institute of Oceanography in England, is used to describe the distribution of

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energy among waves of a different period. Using this concept has allowed the centers of distant storms to be plotted by the energy distribution of the wave according to their synoptic period. Wave information for the Pacific may be obtained from the Office of Climatology (U.S. Weather Bureau, 1961).

CHEMICAL OCEANOGRAPHY

INORGANIC CHEMISTRY

WATER COLUMN

- Dissolved System
- Radioactivity

MARINE GEOCHEMISTRY

- Sediments
- Interstitial Water

ORGANIC CHEMISTRY

WATER COLUMN

- Dissolved Organic Material
- Sediments and Particulates
- Biogenic Material

NUTRIENTS

CHEMICAL OCEANOGRAPHY

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The chemical composition of sea water in DOMES, in terms of its major constituents, is not unique to that region, and therefore many of the observations about the world oceans are applicable. Important general works include Sverdrup et al. (1942), Hill (1963), Riley and Skirrow (1965) and Goldberg (1974). The major constituents of sea water are sodium chloride, sodium and magnesium sulfate, magnesium and calcium carbonate, and potassium sulfate (Culkin, 1965). Seven ions, Cl^- , Na^+ , $\text{SO}_4^{=}$, Mg^{++} , Ca^{++} , K^+ and HCO_3^- , (in that order) comprise over 99% of dissolved sea water constituents. The distribution of minor elements in the ocean has been discussed by Goldberg (1965) and Brewer (1975). The general discussion on mineralogy of deep sea sediments by Arrhenius (1963), by Chester (1965), by Turekian (1965), and by Chester and Aston (1976) are also applicable to DOMES.

Sources of raw data for the chemical oceanography of the DOMES area include reports discussed earlier. Most notable are the research cruises of the R/V Vityaz (Vityaz, 1961), several expeditions originating from Scripps Institution of Oceanography, those of the R/V Thomas G. Thompson from the University of Washington, of the R/V Yaquina from Oregon State University (Byrne, 1969) and, most recently, the 1974 GEOSSECS expedition, Leg 10 (Broecker and Mantyla, 1974), and ongoing Deep Sea Drilling Project expeditions.

INORGANIC CHEMISTRY

WATER COLUMN

Dissolved System. Much of the investigation of the chemical composition of sea water in and around DOMES has involved determination of the content of

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dissolved O_2 , CO_2 , HCO_3^- , and CO_3^{--} , and total salinity. Duedall and Coote (1972) collected data during the Hudson 70 expedition, along the $150^\circ W$ meridian from $63^\circ S$ to $55^\circ N$, reporting new oxygen data for the Pacific Ocean in that region. Dissolved oxygen was observed to be an excellent water-mass indicator because of its characteristic vertical distribution, and also because it is relatively easy to measure. Furthermore, it can be related to other chemical parameters, such as total CO_2 , nutrients, and particulate carbon. The oceanographic features reported by Duedall and Coote are similar to those reported at $169^\circ W$ (Reid, 1965) and at 174° - $176^\circ W$ (Smetanin, 1968). A deep oxygen maximum at 5000 m, observed at several stations, is thought to be associated with a recently-reported bottom current that flows between the Mid-Pacific mountains and the Line Islands (Edmond et al., 1971).

During the winter of 1957-58, the distribution of oxygen and phosphate was measured by Smetanin (1961) aboard the R/V Vityaz. Ten stations in DOMES were included in this survey of the northeast and eastern equatorial Pacific. The distribution of oxygen at depths of 1000, 2000, and 3000 m was mapped, and the oxygen minimum depth was identified.

Pytkowicz and Kester (1966) used oxygen and phosphate as indicators of deep and intermediate water circulation in the same region. Subsequently, they studied degree of oxygen saturation in northeast Pacific surface waters (Kester and Pytkowicz, 1968). Seasonal fluctuations were shown to occur because of variations in temperature and productivity; however, the assumption that surface waters are saturated with oxygen relative to a standard atmosphere was found to be valid within a few percent during the winter.

Keeling et al. (1965) and Keeling (1965) report direct measurements of the concentration of CO_2 in the atmosphere and sea water, from $30^\circ N$ to $30^\circ S$ in the Pacific Ocean, in a broad belt near the equator and approaching the

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coast of South America. The average rate of exchange between the ocean surface and atmosphere was estimated to be $18 \text{ moles/cm}^2 \text{ atm yr}$. This value agrees with global average values derived from other sources. Similar investigations by Miyake et al. (1974) indicated that a large excess of CO_2 in ocean surface waters, compared with atmospheric CO_2 content, occurs in equatorial regions, while a deficit of CO_2 of the water appears in temperate zones. In general, Pacific equatorial waters were observed to be a source rather than a sink of CO_2 in the atmosphere.

Data for the $\text{CO}_2\text{-O}_2$ system obtained from the 1969 GEOSSECS Intercalibration Cruise are consistent with a vertical mixing model for the water masses. However, linear regression analyses of this same data, made without assuming a vertical mixing model, indicate that carbonate reactions are also a factor to be considered (Ben-Yakov, 1972). The model constructed by Kroopnick (1974) demonstrates that in situ consumption of O_2 and concomitant production of CO_2 by marine organisms are also significant factors in deep waters. The ratio of O_2 to CO_2 in sea water is apparently a function of the biomass in these regions and depths. An excess of CO_2 exists at greater depths, in part the result of decomposition of organic material and bacterial CO_2 production. The presence of large populations of flagellated microorganisms at depths down to 5000 m permits inference of O_2 consumption in these waters. In Fanning Island Lagoon, and presumably in other coral reefs, biological processes of CO_2 production and consumption, as well as freshwater dilution, further affect the concentration of CO_2 in sea water (Smith and Pesret, 1974).

The presence of dissolved CaCO_3 in sea water is a control on pH and consequently may regulate a variety of pH-related processes. The distribution of calcium carbonate saturation is related to water depth, with relatively high undersaturation in deep water, high supersaturation around rises, guyots,

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and other shallow regions containing CaCO_3 -rich remains of plants and animals. CaCO_3 in deep sediments is constantly dissolving at rates that differ along a vertical profile (Peterson, 1966). A sharp increase in the rate of dissolution occurs at c. 4000 m, a depth corresponding to the disappearance of calcite in sediments; however, the relation of rate of dissolution to degrees of undersaturation was not clarified in Peterson's study. Pytkowicz (1970) examined CaCO_3 concentration as a function of saturation and compensation depths. The saturation depth, at which waters are 100% saturated, underlies super-saturated waters; at the compensation depth, rate of carbonate solution equals the rate of its sedimentation; below compensation depth, solution exceeds sedimentation. The presence or absence of sedimentary carbonates is in part a function of the chemical properties of the waters, e.g., total dissolved CO_2 , pH, salinity, temperature and pressure (Ben-Yaakov and Kaplan, 1971), and partly controlled by rate-limiting factors such as the size of carbonate crystals precipitating, their mineralogy (aragonite or calcite), the magnesium content of the calcite and the content and nature of organic matrix (Broecker, 1974). Ben-Yaakov et al. (1974a, 1974b) suggested that over extended time scales, the carbonate compensation depth is controlled by the degree of carbonate saturation in the ocean water. Data obtained during these studies indicated a functional relationship between compensation depth and alkalinity and nutrient cycles. Three independent factors were suggested as controlling compensation depth: bottom topography, nutrient recycling through oceanic mixing, and the production of biogenic CaCO_3 as a function of the availability of nutrients.

Culberson and Pytkowicz (1975) analyzed salinity, pH, alkalinity, and the concentrations of silica, phosphate and nitrate of samples taken from 0.6 to 300 m from the ocean floor, in an effort to determine whether concentration

gradients exist in deep water. A statistically significant near-bottom increase in pH was observed, but no other gradients occurred; these findings do not preclude the possibility of gradients resulting from advective transport or slow mixing.

Tsunogai et al. (1973) measured the concentration of calcium and the calcium/chlorine ratios throughout a large area of the Pacific, including DOMES. The variation in calcium content caused primarily by the precipitation of CaCO_3 from surface water and its dissolution in deep water was determined.

Smith et al. (1970) observed that a plume of turbid, CaCO_3 -laden water is expelled from English Harbor at Fanning Atoll with outgoing tides. This plume was interpreted to constitute material produced on the external reef, drawn into the lagoon with incoming tides, and subsequently expelled, resulting in a net accumulation of CaCO_3 in the lagoon.

A variety of other investigations have analyzed sea water for the presence of trace elements. Schutz and Turekian (1965) employed neutron activation analyses in their exploration of geographical and vertical distribution of 18 elements. Sugawara (1969) summarized data obtained from several expeditions of Tokyo Fishery University pertaining to the surface, vertical, and regional distribution of iodine, arsenic, molybdenum and vanadium. Previously it was found that the distribution of iodine forms (iodide and iodate) is dependent upon biological activity (Tsunogai, 1971). Other trace elements analyzed in sea water in or near DOMES include tritium (Dockins et al., 1967), cobalt and nickel (Forster, 1966), chromium (Grimaud and Michard, 1974), boron and chlorine (Uppström, 1974), zinc (Zirino and Healy, 1971) and cesium (Folsom, 1974).

Other trace components of sea water include dissolved gases. Craig et al. (1967) measured samples of nitrogen, oxygen and argon by gas chromatography, and neon and helium by mass spectrometry. They found that nitrogen is

systematically about 2% supersaturated and argon about 1.5% undersaturated, relative to the solubility data of Benson and Parker (1961). Helium, neon, argon and krypton were studied by Bieri and Koide (1972), who found supersaturation of these noble gases to be associated with a nearby salinity maximum of greater than 35‰.

Radioactivity. The presence of radioactive isotopes in the water column, sediments, interstitial water, and also in the biota of the Pacific has been widely investigated over the past decade. None of these studies is specific to DOMES, but some include the region.

Craig (1969) investigated the vertical distribution of C^{14} , observing that at 1.3 km the concentration of C^{14} is constant for all latitudes. The primary focus of these studies was methodological, and was aimed at the use of C^{14} as a tracer of abyssal mixing and circulation. Horizontal variations of C^{14} in bottom water are treated for a flowing open system affected by vertical diffusion from above, particulate flux or consumption, and radioactive decay.

Silker (1972) conducted a similar study of several radionuclides in surface waters at various latitudes. Fallout rates were uniform across narrow latitude belts, with constant concentrations of radionuclides occurring both vertically and horizontally in the water mass, down to the thermocline.

Chung and Craig (1973) constructed profiles for radium-226 from data taken from four stations in the eastern Pacific, one of which was located in DOMES, to test the hypothesis of an internal production of Ra-226 in the ocean. Findings tended to indicate that a small in situ production from sediments may exist in specific areas.

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Other studies, including those of Suess and Bien (1971), Miyake et al. (1973), Saruhashi et al. (1975), and Michel and Suess (1975) have sampled sea water from DOMES and adjacent areas, analyzing it for concentrations of bomb-produced tritium, cesium and C^{14} .

Radionuclides from nuclear explosions are known to have entered the food chain in the world ocean. Palumbo et al. (1966) sampled organisms at island stations including Palmyra, Washington, Fanning and Christmas, in or adjacent to DOMES, to determine levels of beta and gamma emissions. These were small but detectable.

Isotopes of thorium obtained from sediment samples in DOMES indicate that there is movement of radium within the sedimentary column (Bernat and Goldberg, 1969). Subsequently, Somalayajulu and Church (1973) determined the isotopic concentrations of radium, thorium and uranium in interstitial water, and suggested that migration of radium from sediments into surrounding waters occurs.

MARINE GEOCHEMISTRY

Sediments. The sediment types in and near DOMES consist of brown clay, siliceous ooze, coccolith ooze, foraminiferal ooze, and detrital muds. These have been analyzed in a variety of studies. Swanson et al. (1967) described the concentrations of 28 elements taken from box cores north of DOMES, in a study focusing upon interaction at the sediment-water interface. These samples indicated much uniformity throughout the region surveyed. For the DOMES area, site C, Hein et al. (1976) presented a classification of the sediments, while Bischoff and Piper (1976) reported on their chemical composition.

Goldberg and Arrhenius (1958) and El Wakeel and Riley (1961) described the distribution of trace elements in the sediments. Burnett (1971b) analyzed the alkali and alkaline-earth metals, Mg, K, Ca, Rb, Sr and Ba, the transitional

metals, Cr, Fe, Co and Ni, as well as Cu and Zn with which they are often associated. Fourteen samples sites were located in DOMES.

Pavlova and Shishkina (1973) observed high iodine concentrations in superficial sediments of shelves and continental slopes throughout the Pacific, notably in regions of high biological productivity, with redistribution between sediment and interstitial water occurring in the process of diagenesis.

Subsequently, Gromov (1975) investigated the absorption of Fe, Ni, Co and Mg from sea water by carbonate sediment, diatom ooze, hydrogenic sediment and red clay. The selective absorption of manganese by hydrogenic sediment may be attributed to the formation of chemical compounds of manganese (minerals) in the sediment.

Investigations have explored the processes leading to distribution and redistribution of the rare earths in bottom sediments and in iron-manganese concretions (Volkov and Fomina, 1973). Exchange constants of calcium and magnesium against sodium and potassium in red clays indicate a much higher rate of exchange for sodium (Rutkovsky, 1973).

The chemistry of manganese nodules has been described in detail by Chester (1965) and by Mero (1965). More recent summaries of their composition are given by Cronan (1972), in a paper which appeared with several others dealing with the chemistry of the manganese depositing environment in Horn (1972). The most recent analyses are by Monget et al. (1976). The mineralogy has been described by Arrhenius (1963), who lists the main structural elements as δ -manganese dioxide, manganese (II) manganite, and iron (III) manganite; in nodules deficient in manganese, substantial amounts of goethite may be present. Manganese (II) manganite exhibits a double layer structure containing Mn (IV) coordinated with oxygen in the main layers, which are separated by c. 10\AA , and contain between them a disordered sandwich layer of Mn (II) coordinated with

O^{2-} , OH^- and H_2O . In nodules which contain iron, the Mn (II) is replaced by Fe (III) to form ferric manganite. In addition, some of the Mn (IV) may also be replaced by Fe (III) with the consequent development of a charge. In nodules containing more iron than can be held in this type of lattice, the excess iron is accommodated as the hydrous oxide, part of which may be converted to goethite. The Mn (II) in the disordered layers may also be replaced by other polyvalent ions, e.g., Co^{2+} , Ni^{2+} , etc.; this probably explains the high concentration of trace elements in the nodules.

Regional variations in the composition of manganese nodules occur in the Pacific, Indian and Atlantic Oceans. Manganese, nickel and copper attain maximum concentrations in deposits from the east of each ocean and decrease in concentration toward the west, while the converse is found for Fe, Co, Ti and Pb. Exceptions include the Mexican continental borderland where deposits are rich in manganese but low in nickel and copper, and elevated submarine volcanic areas which, irrespective of their location, seem to contain deposits similar in composition.

On a worldwide basis, regional variations in nodule composition can probably be related to the proximity of the deposits to potential sources of metals, and to the nature of their environment of deposition.

Interstitial Water. Presley *et al.* (1967) analyzed the interstitial waters of marine sediments to determine the concentrations of manganese, nickel, iron, cobalt, sodium and lithium in a wide region of the Pacific slightly to the east of DOMES. These trace elements showed a wide variety of distribution patterns, apparently related to the oxidizing or reducing characteristics of the sediments.

The most recent studies of interstitial waters are being carried out under the NSF-IDOE Manganese Nodule Project. Callender *et al.* (1975) and Callender

and Bischoff (1976) reported on trace elements in interstitial water in the DOMES area, describing the vertical distribution of Mn and Cu extracted from the three major sedimentary provinces. Bowser et al. (1975) reported on the nutrients and dissolved oxygen in the interstitial water at 140°W and 10°N from samples collected by NSF-IDOE cruises Mn 74-01 and Mn 74-02 and a NOAA DOMES cruise in 1975.

ORGANIC CHEMISTRY

WATER COLUMN

Dissolved Organic Material. The dissolved organic material in sea water has not been completely characterized. One fraction consists of compounds typically associated with biochemical processes of living organisms, notably the amino acids. Lee and Bada (1975) analyzed sea water samples in a region just east of DOMES. They reported that dissolved free amino acids made up only 0.3% of the dissolved organic carbon (DOC); however, substantially larger amounts of combined amino acids were present. Concentration variations of the combined amino acid fractions in the water column suggest their potential use as water-mass indicators.

During the 1969 cruise of the R/V Hakuho Maru, passing through DOMES, samples of water were analyzed for DOC to a depth of 5340 m (Ogura, 1970). The data indicate striking homogeneity of DOC distribution horizontally and vertically, possibly as a function of large-scale circulation patterns.

Samples of low-molecular-weight hydrocarbons, obtained in DOMES, indicated that a slight correlation exists between chlorophyll a and ethylene and propylene, but not with methane, ethane or propane (Lamontagne et al., 1974, 1975).

Williams and Robertson (1975) sampled surface film at stations located north and also east of DOMES, analyzing the collected water for the presence of

chlorinated hydrocarbons, notably DDT residues and PCBs. As was anticipated, the concentration of these substances was found to be much higher closer to land than in the open sea.

The content of organic material may be localized, as in Fanning Island Lagoon. Here, a total carbon budget, including particulate organic carbon, was constructed from measurements taken from within the lagoon (Gordon, 1971b). The high concentrations of total and particulate organic carbon, 1.68 mg/l and 80 µg/l respectively, are the result of high biological productivity in the lagoon. However, because of the low flushing rate, this unusual environmental factor has little effect on the surrounding ocean.

Sediments and Particulates. The distribution and composition of the particulate matter of various regions of the world ocean has been described by Holm-Hansen (1972), who discussed the C/N ratio found in tropical waters as well as arctic and temperate waters. Gordon (1971a) analyzed C/N ratios near DOMES, observing that the ratio increased with depth, probably as a function of the fact that marine organisms utilize protein more readily than carbohydrates. Handa et al. (1972) suggested that temperature and concentrations of inorganic nutrients have a major influence on the composition of organic particles.

Samples obtained aboard the R/V Hakuho Maru (KH-69-4) indicated a high concentration of particulate matter near the surface, with concentration minima at 150 m to 250 m (Ichikawa and Nishizawa, 1975). Regional variations in concentration were noted, and a rapid downward transport was postulated.

Agatova and Bogdanov (1972) observed a change in the composition of particles with depth. Lipids, being fairly stable compounds, tended to remain intact; proteins and nucleic acids were more easily hydrolyzed, whereas

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carbohydrates interacted with other organic compounds to form humic substances. Water-insoluble polysaccharides predominate in the composition of suspended carbohydrates, accounting for 77.9% of their composition (Artem'yev, 1973). These consist for the most part of reserve and structural portions of planktonic organisms, the primary source of organic material in the ocean.

Organic carbon, nitrogen and carbohydrate distribution in the sediments in and around DOMES indicate that the process of destruction of organic matter is controlled largely by the amount of dissolved oxygen concentration in bottom water (Gross, 1967b). Romankevich (1968) suggested that distribution patterns were subject to climatic and circumcontinental zonation. Carbohydrate distribution in sediments was apparently unrelated to primary productivity by planktonic organisms in the overlying water column (Artem'yev, 1970).

Bonnar (1975) measured nitrogenous compounds obtained from sediment cores near and within DOMES. Findings indicate that local conditions may influence the distribution of these compounds, and give rise to wide variations in the distribution profiles.

Humic and fulvic acids are major components of the more recent marine sediments, and may be a reservoir for organic carbon there. Nissenbaum and Kaplan (1972), working with samples obtained from locations representative of the world oceans, observed evidence for in situ origins of humic substances. Using deuterium as a tracer, Nissenbaum (1974) collected further data in support of the authigenic nature of marine humates.

Biogenic Material. Biogenically released elements are an important component of the organic constituents of the water column and sediments. Organic chelators are known to be a factor affecting primary production, the source of most organic material in the ocean (Barber and Ryther, 1969). Furthermore,

organic fixation of metals has been found to be a significant process for incorporating them into sediments (Burnett, 1975). Much of the sediment throughout the world ocean is composed of material derived from the tests of Foraminifera, both recent and fossil (Riedel and Funnell, 1964). The interstitial solutions throughout the Pacific contain ammonia, silica and phosphates produced by the in situ microbiological degradation of marine organisms (Brujewicz and Zaitsev, 1964).

NUTRIENTS

The significant nutrients found in sea water are silica, phosphate, and the nitrogen compounds.

The distribution pattern of silica, as described by Lisitzin and Bogdanov (1968), falls into enrichment belts, one of which passes through equatorial regions in the vicinity of DOMES. The particulate silica of the sea is primarily of marine biogenic origin, with little terrestrial contribution (Kido, 1974). Alterations in the physical and chemical properties of biogenic silica on the sediment floor have been studied in detail by Hurd and Theyer (1975).

Wooster (1953) characterized the distribution of phosphate-phosphorus in the iso-phosphate, transition, high-phosphate and deep-phosphate layers. Yoshimura (1972) found an area rich in organic phosphate in equatorial regions along the 170°W meridian, and observed that in surface waters of tropical regions, the ratio of organic to total phosphorus is high.

The distribution of nitrogen compounds and processes of denitrification and nitrate uptake are the subjects of much of the research on sea water nutrients pertinent to DOMES. A maximum in the vertical distribution of nitrite-nitrogen was observed by Harvey (1955) in or just above the thermocline. This

phenomenon has been attributed to the microbiological oxidation of ammonia from decomposing organic matter. Thomas (1966a), in studies on waters near DOMES, and Wooster (1967), examining samples from stations within DOMES, reported a second nitrite maximum, associated with low concentrations of dissolved oxygen and high salinity, both features of equatorial Pacific waters.

Oxygen is known to be an inhibitor of the denitrification process because of its effective competition with nitrate as an electron acceptor. Goering (1968) demonstrated that nitrite and N_2 are produced from nitrate in the oxygen minimum layer. Release of N_2 may result in a loss of combined nitrogen from the ocean, unless recaptured through nitrogen-fixation. In the presence of oxygen saturation, denitrification decreased by 58%. The findings of Cline and Richards (1972) are similar. Codispoti (1973) continued these previous lines of investigation, mapping temperature, salinity, oxygen content, and nitrate concentrations throughout the eastern tropical north Pacific.

The capacities for nitrite production from nitrate, and consumption of nitrite, are considerable in surface layers shallower than 30 m. The rates of both these processes are increased by illumination, therefore assigning the reductive capacity to phytoplankton (Hattori and Wada, 1971; Wada and Hattori, 1971, 1972). Cline (1973) and Cline and Kaplan (1975) measured the various isotopic fractionations and nitrogenous products associated with denitrification. Denitrification appears to be the major respiratory process observed within the oxygen minimum zone in the region under investigation, to the east of DOMES.

This process and its kinetics were previously investigated by MacIsaac and Dugdale (1969), who applied the Michaelis-Menten equation to nitrate and ammonia uptake by phytoplankton. Yamada (1973) examined various biological processes which could lead to the formation of nitrite, including nitrification,

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assimilatory and respiratory reduction of nitrate by bacteria, and assimilatory reduction of nitrate by phytoplankton. Samples were obtained from a station at 156°55'W, 20°41'N, at the edge of DOMES. Findings indicate that phytoplankton, rather than bacteria, are responsible for the accumulation of nitrite in the tropical nitrite band.

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BATHYMETRIC EXPRESSIONS

The Pacific Ocean basin floor can be divided into four major categories: (1) abyssal floors, (2) mid-ocean rises, (3) seamounts and guyots, and (4) trenches. Abyssal plains, hills, abyssal gaps and mid-ocean canyons are included in the first category; these occupy the deepest part of the ocean (Heezen et al., 1959). Abyssal plains are areas of the deep ocean floor with minor bottom relief. They are found in all oceans at the foot of the continental rise. Abyssal gaps are constricted passages connecting two abyssal plains which, in the vicinity of the gap, lie at different levels. Abyssal hills are small hills rising from the ocean floor, less than 1 km in relief and often dome-shaped. They represent the principal topographic feature over 60% of the sea floor in the Pacific, including the area between the Clarion and Clipperton fracture zones (Menard, 1964). Mid-ocean canyons have steep walls and flat floors, are 1-10 km wide, and range from a few fathoms to over 200 m in depth. Ocean rises are large areas rising several kilometers above the surrounding abyssal floor. Seamounts, normally volcanic in origin, are any isolated submerged features that rise more than 200 m above the sea floor. Guyots, a special subdivision of seamounts, are characterized by broad, flat tops. Trenches are long (hundreds of kilometers), narrow (1-100 km), linear depressions with depths to 10000 m that lie along the base of island arcs or Andean-type coasts. Other features include fracture zones and depressions, additional negative topographic features of the ocean floor which may serve as sites for the accumulation of sediments.

The overall topography of the Pacific is most clearly shown by bathymetric maps and charts. Emery and Shekhvatov (1966) presented a review of bathymetric charts of the Pacific Ocean that have been published in various countries since World War II, particularly a chart of the entire Pacific Ocean compiled by G.B. Udintsev at the Institute of Oceanography, Academy of Science USSR, which incorporated data from Soviet expeditions and those of other countries. More recently, Scripps Institution of Oceanography has published a set of maps showing the bathymetry of the north Pacific (Chase et al., 1970) including three (sheets 7, 8, 9) that cover the DOMES area. Menard and Chase (1971a) published a bathymetric atlas of the north central Pacific that consists of 74 bathymetric charts covering the north central Pacific Ocean from 4°S to 62°N and 160°E to 140°W, and another (Menard and Chase, 1971b) of the northeastern Pacific, consisting of 41 charts covering the area from 4°S to 60°N and 140°W to the American coastline. Sea floor relief is shown by means of 200 fathom contours based on a mean sound velocity of 4800 ft/sec, and where data permits, the 100 and 20 fathom contours are shown. From a set of detailed bathymetric charts of the central Pacific, Roberts (1968) contoured the mean topography of the Mid-Pacific Mountains. Larina (1975) compiled a map of the mountains of the Pacific Ocean, based on recently obtained data. He concluded that the number of mountains higher than 1 km and hence the scale of volcanism in the Pacific Ocean is at least 1.5 times smaller than Menard supposed.

Individual topographic features within DOMES have been described in the literature. The Scripps Institution of Oceanography-Navy 1950 expedition to Bikini and the Mid-Pacific Mountain area crossed the western section of DOMES (Hamilton, 1956). The expedition explored five guyots: the Cape Johnson Guyot, Hess Guyot, Horizon Guyot, Guyot 20171 and Guyot 19171. The paleontology and geologic history of the guyots are discussed. Roberts (1968) syn-

thesized map data and studied aspects of guyot topography and subsidence. Karig et al. (1970) seismically profiled several guyots in the DOMES area, using data collected from Scripps expeditions. Emery (1956) described the topography, composition and water characteristics of the shallow water platform surrounding Johnston Island, located in the western portion of DOMES. A significant review of the physiographic characteristics of DOMES area site C (16.5°N-13.5°N, 127.5°W-124.5°W) has been presented by Piper (1976).

ORIGINS

Most topographic features of ocean basins arise from: (1) volcanism, (2) interactions between crustal plates, (3) tectonic movement, (4) deposition, and (5) combinations of the above. The origin of abyssal hills topography appears to be the result of volcanism and faulting, and of sedimentation and erosion. This is discussed by Luyendyk (1969, 1970), who studied two hills in the northeast Pacific, a little north of DOMES. He proposed a primarily volcanic origin for the western hill; the eastern hill arose from a faulting of the oceanic crust. Volcanic evidence has been observed in the Pacific since Darwin, and probably even earlier.

North Pacific sediment layers were measured by seismic profiling by Ewing et al. (1968). Major sediment accumulations were found in a belt approximately following the equator and along the western and northwestern basin margins. There is a marked decrease in thickness over the crest of the East Pacific Rise. Sediment thickness in the DOMES area ranges from a maximum of 600 m in the west to almost zero in the eastern portion. Sediment thickness in abyssal hill areas shows a strong relation with bathymetry. Sediment was found to be thickest in valleys and sparsest on tops of abyssal hills by Moore and Heath (1967). These authors described the morphology of abyssal hills in the central

equatorial Pacific within DOMES, where most hills and valleys are elongate and tend north-south. This is approximately parallel to that of inferred magnetic anomalies (Menard and Mammerickx, 1967). Mudie et al. (1972) discussed the origin of several small graben-like troughs in the eastern DOMES area, at 13°45'N and 126°13'W, and tentatively interpreted them as the result of tensional separation at the tops of the area's abyssal hills. The troughs are believed to be caused by down-slope creep and consolidation of pelagic sediments.

The origin of three parallel chains of seamounts in the Baja California Seamount Province is discussed by Hey and Morgan (1971). The seamounts are thought to have been formed by the movement of the Pacific plate over three hot spots fixed in the mantle. Maxwell (1958) described the heat flow regimes and the outflow of heat from under the Pacific Basin. Menard (1967), discussing fracture zones in the northeastern and central Pacific, particularly the Clipperton fracture zone in the DOMES area, suggested that the fracture zones of the central Pacific are part of the same system as the northeast Pacific zones.

STRATIGRAPHY

CENOZOIC SEDIMENT STRATIGRAPHY AND COMPOSITION

The most recent and extensive record of Cenozoic sediment from the DOMES area comes from cores collected by the R/V Glomar Challenger in the Deep Sea Drilling Project (JOIDES Program) sponsored by the National Science Foundation. Legs 5, 9, and 16 crossed the DOMES area and were reported on by McManus et al. (1970), Hays et al. (1972), and Van Andel et al. (1973), respectively. They show that sedimentation during the Cenozoic has been similar to the current environment, and consists mostly of CaCO_3 . Changes in properties of the en-

vironment were summarized by Van Andel et al. (1975), who described the Cenozoic history and paleoceanography of the DOMES area. From the Eocene to the present, the zone of maximum sediment deposition has been in an area roughly parallel to the equator. Prior to the Eocene, this zone had moved northward with increasing geologic age. A domination by siliceous sediments changes to a domination by calcareous sediments at the Eocene-Oligocene boundary. Calcareous deposits decrease with increasing depth while siliceous deposits increase. Inferences about ocean basin age, plate rotation and changes in spreading rate were derived from sediment cores. The history of the carbonate compensation depth and the major erosional phases in the deep Pacific are discussed. Historical reasons for changes in sediment character are given.

Heezen and MacGregor (1973) discussed the evolution of the Pacific Ocean, drawing on data from the Deep Sea Drilling Project and from previous work done on sea floor spreading and continental drift. New crust is formed on the East Pacific Rise above the carbonate compensation depth. It moves both laterally and downward, accumulating both biogenic and detrital sediments until it is carried below the compensation depth. Below this depth, inorganic clays are accumulated as a result of removal of carbonate by solution.

Kierstead et al. (1969), who studied equatorial Pacific deep sea cores, identified 2 Upper Pliocene and five post-Pliocene zones. Hays et al. (1969) also studied the equatorial Pacific, and used magnetic stratigraphy to date Pliocene-Pleistocene sediments. Inferences are drawn as to their biostratigraphy and climatic record. Kobayashi et al. (1971) did similar work slightly further to the west. Burkle (1971) constructed a chronostratigraphic and paleoclimatic framework to permit diatom analysis of Late Cenozoic equatorial Pacific sediment cores.

The classic description of the chemical and mineralogical composition of pelagic sediments in the east Pacific has been provided by Goldberg and Arrhenius (1958). More recently, Heath (1968, 1969c) described the mineralogy of deep-sea sediments of the equatorial Pacific. Northern equatorial sediment ranging in age from Eocene to Late Miocene has as its principle constituent a component derived mainly from tholeiitic debris. This igneous component is characterized by abundant montmorillonite, intermediate plagioclase, and the zeolites phillipsite and clinoptilolite. Southern and western equatorial samples younger than Late Miocene are rich in pyroxene and chlorite and have high pyroxene:plagioclase ratios in 2-20 micron particle size fractions. The bulk of this material is derived from island arcs which form the western margin of the Pacific basin. Eolian-derived sediments, rich in quartz and illite, are abundant in northern equatorial sediments of Quaternary age. Fine fractions of periglacial continental loess deposits are the source of the debris. Contrastingly, Tertiary sediments contain less than 20% of this material. Within pre-Pliocene deep-sea carbonate sediments, coccoliths and discoasters predominate, whereas younger Cenozoic carbonates have a higher proportion of foraminiferal tests.

STRATIGRAPHIC CONTROL OF Mn NODULES

Menard (1976) correlated the occurrence of manganese nodules with basin stratigraphy based on the available sample data. Nodules occur in only 12.4% of calcareous ooze samples, but are in 42.6% of siliceous clays. The probability of finding buried manganese nodules in JOIDES cores in the eastern equatorial Pacific is greatest in Eocene sediments and at times of intermediate sedimentation rates ($4-8 \text{ m}/10^6 \text{ yrs}$). Photographs and cores taken in the DOMES area of Tertiary outcrops having patchy manganese pavements showed that

Oligocene sediments are more likely to have nodules than Miocene sediments. It was concluded that nodules were more abundant in the Tertiary at the sediment surface than they are now. Nodules now on the seafloor are essentially fossil lag gravels. Nickel, and possibly copper and manganese, are the most concentrated in mid-Tertiary sediments.

Moore (1970) also noted an abundance of manganese nodules in Tertiary sediments. Core samples were taken from a small area of abyssal hills in DOMES, at 10°N and 153°W, by the WAHINE expedition from the Scripps Institution of Oceanography. Tertiary outcrops occur in the hills where the overlying Quaternary material is thin and eroded away. Manganese nodules were found to be most common on the slopes. Moore suggests that a series of terraces were formed by step faults in the late Tertiary, and that the terrace trapped sediments and concentrated manganese nodules.

The origin of manganese nodules has been discussed at length. Bonatti et al. (1972) presented a classification system for Mn nodules based on their place of origin. Hydrogenous deposits are prevalent on ocean basins where well-oxidized pelagic sediments accumulate at low rates and at topographic highs with little or no sedimentation. Diagenetic deposits are important in hemipelagic regions of the ocean. Hydrothermal deposits are prevalent in areas of active volcanism, especially near rises and rifts. Halmyrolytic deposits are found where basalt debris is subjected to submarine weathering.

Several mechanisms are proposed for keeping Mn nodules at the surface:

- (1) Mn nodules migrate upward at the same rate as the surface (Menard, 1976),
- (2) surfacial sediments erode after a period of rapid deposition (Menard, 1976),
- (3) nodules are rolled by bottom currents (Bender et al., 1966), and
- (4) they are nudged upward by benthonic organisms (Menard, 1964).

MODERN SEDIMENTATIONSEDIMENT ORIGIN

The water column contains particulate matter ranging in size from 1 to 100 microns. Included in these particles are aggregates of terrestrial clay, dust and aerosols from the air which have settled into the water, volcanic ash in particulate form, metal oxides resistant to dissolution, and skeletal material of certain marine plants and animals prior to dissolution. Small bits of plastic and other man-made substances also float on the surface of the water or may be suspended at various levels in the water column with the natural particulates.

Several papers relevant to the study of particulate matter in DOMES are contained in Bischoff (1976) who compiled a major report on site C. This report provides important baseline information on the sediment system, as well as laboratory studies conducted to predict how resuspended sediment might interact with surface sea water and how rapidly sediment might settle out. The Preliminary Geosecs Report for Leg X (Broecker and Mantyla, 1974) reports uncalibrated shipboard data for light-scattering using in situ instrumentation which may later be related to the particulate load in the ocean. However, Sheldon et al. (1972) obtained samples from surface and deep waters of the Pacific Ocean, and determined distribution of particle size. The size distribution varies geographically and with depth, with roughly equal concentrations of material occurring at all particle sizes. According to these investigators, most suspended particulate matter is associated with non-living organic matter or with organisms, rather than with inorganic, nonbiogenic entities. Carder et al. (1971) discussed particle size distribution in an area which includes the southeast part of the DOMES region.

SEDIMENT CLASSIFICATION AND DISTRIBUTION

Revelle et al. (1955) distinguished between 4 main types of pelagic sediments in the Pacific Ocean. These are (1) red clays, (2) calcareous ooze, (3) radiolaria ooze, and (4) diatom ooze. Radiolaria and diatom ooze are siliceous. Clays cover roughly half the ocean area due to the great depth of the North Pacific Basin. Calcareous oozes occupy nearly as great an area and are found at shallower depths, where dissolution rates are low, and below the equatorial zone of the east Pacific, where biological productivity is high. Radiolarian oozes border the northern fringes of the eastern equatorial calcareous zone. Diatom ooze forms bands in the northern Pacific and Antarctic oceans.

Van Andel et al. (1975) discussed distribution of calcareous and siliceous sediment in the eastern equatorial Pacific, in an area which roughly corresponds to the DOMES area. Deposits grade from highly calcareous near the equator to essentially carbonate-free opal around 20°N.

Sediment distribution in the Hawaiian archipelago (whose southern half lies in the DOMES area) was studied by Fan and Grunwald (1971). They differentiated between four sediment types: (1) shallow-water carbonates and detritus around the islands, (2) calcareous oozes on bathymetric highs distant from shore, (3) brown clay on the Hawaiian Arch, and (4) siliceous ooze in the Hawaiian Deep and west of the island of Hawaii.

Heath (1969a) identified three types of non-biogenous clastic sediments: (1) "Oceanic" debris, consisting of tholeiitic volcanic material, (2) "Island arc" debris, consisting of andesitic material, and (3) "Continental" debris, consisting of terrigenous material.

Moore (1969) discussed late Cenozoic sedimentation in an abyssal hill area in the equatorial Pacific within DOMES. He noted that recent sediments

are thickest not in the valleys but on the slopes, due to small topographic irregularities on the slopes of the abyssal hills that act as sediment traps.

SEDIMENTATION PROCESSES

Sedimentation in the world ocean has been discussed in a major review paper by Lisitzin (1972). Samples collected from the Pacific by the R/V Vityaz and more recent Soviet cruises permit the study of processes that determine the formation of sedimentary deposits, their size, mineralogic composition, and geochemistry.

Sedimentary processes in the central Pacific were discussed in general by Davies and Gorsline (1976). Central Pacific basins are generally starved of terrigenous sediments, which are trapped in ocean trenches on the margins of the Pacific Basin. Biological productivity, the carbonate compensation depth, bottom currents, eolian transport and volcanism are the important factors controlling sedimentation. Due to upwelling, the eastern equatorial Pacific is one of the most biologically productive areas in the world. Biogenous material dominates the sediment species. Because the Pacific Ocean is generally undersaturated with respect to silica, siliceous biogenous sediments dissolve rapidly after the death of an organism. Therefore, they can only be deposited where the rate of supply exceeds the rate of dissolution.

Siliceous microfossils in surface sediments of the eastern tropical Pacific were found to be better preserved in an area near 10°N, 117°W than in equatorial sediments, and at deeper sites in most latitudes. This was attributed primarily to sediment redistribution processes (Johnson, 1974). Diatoms contained in membrane-enclosed fecal pellets may escape dissolution (Schrader, 1971).

Carbonate sediments predominate because of undersaturation with respect to silica. The rate of dissolution of calcium carbonate varies with depth, being most rapid from below the lysocline to the carbonate compensation depth (CCD). The CCD is depressed below areas of high biological productivity. Foraminiferal evidence indicates that dissolution is intensified during interglacial periods (Berger, 1973). This had been ascribed to a lag in oceanic responses to climatic change (Pisias et al., 1975). The CCD has risen from 5200 m in the Oligocene to an average present value of 4700 m; this rise reflects the effect of decreasing bottom water temperatures on calcium carbonate solubility (Heath, 1969b; Van Andel and Moore, 1974). Coccoliths that are contained within fecal pellets may be preserved at least temporarily below the CCD (Honjo, 1975). Berger (1975) discussed dissolution profiles for Foraminifera.

Turbidity currents, flows of dense, mud-rich water, are another mechanism of transport in the deep ocean. Lineberger (1975) discussed the formation of pelagic turbidities in the eastern central Pacific basin, covering the DOMES area at 170°W-155°W and 0°-10°N. Bottom currents may be important mechanisms for redistribution of sediments. Detailed studies of sediment erosion and redistribution within DOMES were reported by Johnson and Johnson (1969, 1970) and by D.A. Johnson (1971, 1972b). It was found that bottom currents have significantly influenced the sediment distribution pattern in the abyssal hills region. Moore (1968) also discussed sediment deposition and resuspension on abyssal slopes in this area. Lonsdale et al. (1972) reported that scouring and sediment redistribution on Horizon Guyot was due to locally-accelerated tidal currents, and Dangeard and Lonsdale (1972) recorded bottom currents and erosion at Horizon Guyot.

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Richards and Hamilton (1967) studied the consolidation of pelagic sediments. Cores show overconsolidation at depths of 0.5-1 m, and then less consolidation with decreasing depth.

Eolian transport may be an important source of sediment in deep ocean basins (Davies and Gorsline, 1976). Clay mineral assemblages in atmospheric dusts from the north Pacific (somewhat north of DOMES) are similar to those of deep sea sediments from the same area (Ferguson et al., 1970).

Volcanoes are important contributors to deep water sediments. Altered volcanic ash is a major component of Pacific red clays. Sediments enriched up to ten times normal values in ore-forming metals were found on the crest of the East Pacific Rise. Areas of enrichment correspond to areas of high heat flow. It is thought that these precipitates are caused by ascending solutions of a deep-seated origin, which are probably related to deep magmatic process (Davies and Gorsline, 1976; Bostrom and Peterson, 1967). Finally, the physical structure of the surface of marine sediments, including those sampled within DOMES, has been modified by burrows produced by bottom organisms, most of them as yet unidentified (Donahue, 1971). Burrowing often results in sediment mixing, as overturned sediments from below are made available for chemical reactions at the sediment-water interface.

SEDIMENTATION RATES

Ionium-thorium chronology (Goldberg and Koide, 1958) has been used to determine that sedimentation rates in the east Pacific decrease with depth and are uniform. Sedimentation rates in the central equatorial Pacific are slow, 1.4-3.5 times lower than the average for all pelagic sediments (Heath et al., 1970). They are controlled by: (1) calcium carbonate solution with increasing depth, and (2) northward and southward decrease of productivity

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away from an equatorial maximum (Van Andel and Whaley, 1974). Rates of manganese accretion on the Waho Shelf (Morgenstein, 1972a, 1972b) are 2-3 times faster than normal deep sea rates. There is considerable fluctuation of growth rates. Pelagic sediment on the Waho Shelf is rare. Somayajulu et al. (1971) studied accumulation rates in the central equatorial Pacific, and reported that nodules accumulate at similar rates, but cease to grow when buried.

PHYSICAL PROPERTIES OF SEDIMENTS

Only in the past 10 years has much attention been given to mass physical properties of deep-sea sediments. A series of reports for the Naval Undersea Research and Development Center by Hamilton (1969a, 1969b, 1969c) were concerned with sound velocity, elasticity, and related properties of marine sediments from three major environments in the north Pacific. Hamilton (1970, 1971) discussed the acoustical properties of marine sediments. Methods of converting laboratory values to in situ values and for the prediction of in situ values are developed for the following parameters: (1) sound velocity, (2) sediment porosity, and (3) sediment density. Sediment types and their properties from abyssal plains and hills can be predicted with some confidence. It is believed that the work, though done on north Pacific sediments, is applicable to the DOMES region.

The mass physical properties of deep sea sediments in the Hawaiian area, close to DOMES, have been studied by Cropper (1968). Keller and Bennet (1973), as reported in the Leg 16 Initial Report of the Deep Sea Drilling Project, studied the mass physical properties of sediment from the Panama Basin and the northeastern equatorial Pacific, including the DOMES area. There is no apparent relationship between variation of mass physical properties and the

age of the sediment or sedimentation rates. Depth of burial is the single greatest factor influencing physical properties. Earlier papers on the mass physical properties of pelagic sediments within DOMES include Keller (1969a, 1969b), Keller and Bennet (1970), and Horn et al. (1968).

Richards and Parks (1975) reviewed the literature on sediment stability, consolidation and bioturbation-geotechnical interactions in the benthic boundary layer. Richards and Hamilton (1967) reported an investigation of mass physical properties of deep-sea sediment cores as the third part of a series begun earlier by Richards (1961, 1962) of mass physical properties of cores taken from the Atlantic, Mediterranean, and Pacific. The report on the Pacific cores is relevant to the DOMES area.

Lonsdale et al. (1971), and Lonsdale and Southard (1974), used flume studies to determine threshold velocities for the erosion of north Pacific red clay. Benthic organism activities may account for observations of erosion of clays in currents with lower than flume-determined threshold velocity. Threshold erosion is substantially lower when roughness elements are present on the sediment surface.

COMPOSITION OF SEDIMENTS

Components of surface sediments in the eastern equatorial Pacific, particularly the Panama Basin to the southeast of DOMES, have been investigated by Kowsmann (1973) as a part of a comprehensive study of the distribution of deep-sea sediments initiated in 1968 by the Department of Oceanography at Oregon State University.

The solution rate of biogenic opal in near-surface sediments of the central equatorial Pacific (DOMES area) is 3-8 times lower than in laboratory studies. Iron, magnesium and calcium aluminosilicates may be forming on the

surface of the opal, reducing its solution rate. The scale of the system suggests that diffusive and not advective processes are primarily responsible for the removal of dissolved silica in sediments (Hurd, 1972, 1973).

Clay mineral constituents were analysed from cores taken from the north Pacific. Illite was more dominant in pelagic samples than near-shore samples, while the reverse was the case for montmorillonite. Chlorite was more abundant in higher latitudes. The kaolinite fraction was minor. Samples were taken during the cruise KH-70-2 of the R/V Hakuho-Mar, including a station at 17.6°N and 146.14°W within DOMES. Montmorillonite taken from a core at this station was found to be particularly rich in iron (Aoki and Sudo, 1972). Aoki et al. (1974) described the mineralogical properties and origin of this iron-rich fraction. Illite and montmorillonite in the Hawaiian Island area were found to be forming from eroded tropically-weathered basalt (Moberly et al., 1968). Chlorite analysis of red clay containing illite and chlorite at 25°N and 165°W, close to DOMES, was discussed by Carrol (1969), and compared with that in grey clay from the Aleutian Trench.

Zeolites in Pacific pelagic sediments are formed by the alteration of palagonite by sea water (Bonatti, 1963; Czyscinski, 1973). Palagonite is a type of partially devitrified glass produced by the interaction of hot basic lavas with cold water. Preliminary data indicated that the zeolite phillipsite occurs in at least the northwest portion of DOMES, accounting for 2%-10% of the carbonate-free sediment (Bonatti, 1963).

Quartz in the central and north Pacific basin was studied by Rex (1958), who found that volcanic and detrital quartz contribute little to the sediments. Detrital quartz is found almost everywhere in concentrations of up to 30%. Quartz concentrations in abyssal plains decrease away from land. Turbidity currents transport quartz within abyssal plains and trenches. Upper tropo-

spheric winds transport quartz to the waters over the province of hilly topography. A map of Pacific quartz distribution in Bonatti (1963) showed quartz concentrations in the DOMES area to range from less than 2% near the equator to greater than 16% in the northeast corner.

Trace metal analysis of cores taken from the Darwin Rise area showed Ba and Cu to be enriched in areas of high organic productivity. The average K/Rb ratio was only slightly higher than the average crustal value. Cr was found to be enriched in some volcanic sediments (Burnett, 1971a).

The occurrence of phosphorite in central Pacific sediments near the Mid-Pacific Seamounts was noted by Bezrukov et al. (1969), on the 43rd cruise of the R/V Vityaz. Palygorskite, a magnesium mineral, was found near the DOMES area during a study of clay minerals in cores obtained in deep sea drilling on Leg 6 of the Glomar Challenger cruises. It is believed to be formed in situ (Gorbunkova, 1972).

Metal spherules from central Pacific Ocean sediments were studied by Friedrich and Schmitz-Wiechowski (1976). Most of the spherules were of meteoritic origin and contained up to 60% Ni, 37% Fe, 12% Cr, and 3% Co.

The chemical composition of organic matter in ocean basin sediment was studied in several areas (including the central Pacific) by Bordovskiy (1974). Organic matter from ocean basins is of a type analogous to dispersed organic matter from sedimentary rocks. Several new forms of organic matter appear during sedimentogenesis. The conversion of organic matter to reduced states is accompanied by the accumulation of cyclic carbon structures.

Organic matter coats carbonate sediment grains, producing a nitrogen- and phosphorous-rich, protein-like structure. This layer may be involved in the calcification of sediments (Suess, 1973).

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BIOLOGICAL OCEANOGRAPHY

PLANKTON

DEFINITIONS AND GENERAL ECOLOGY

PHYTOPLANKTON

WITHIN DOMES

NEARBY DOMES

ZOOPLANKTON

BIOMASS

VERTICAL DISTRIBUTION

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BIOLOGICAL OCEANOGRAPHY

PLANKTONDEFINITIONS AND GENERAL ECOLOGY

Planktonic organisms, defined as those which are freely drifting and unable to maintain their position against strong, directional currents, include a large diversity of species, mostly very small and even microscopic in size. Larger surface-living and floating organisms such as jellyfish are included in the plankton; however, for purposes of this literature review, the surface biota are categorized as pleuston and neuston, and are dealt with in that section.

Plankton may be further categorized as bacterioplankton (including all non-animal heterotrophs), phytoplankton (plants) and zooplankton (animals). This latter category includes larvae of animals which are effective swimmers as adults (nekton). Ekman (1953) and Hedgpeth (1957b) term epiplankton those organisms living in the upper water layers, from the surface to 150-200 m; mesopelagic and bathypelagic plankton inhabit the depth zones from 200-1000 m and 1000-4000 m, respectively. Holopelagic organisms remain passively drifting throughout their entire life cycles, as distinct from meropelagic (meroplanktonic) forms which occur only temporarily, during limited life history stages of development.

Plankton fall into several operationally-defined size classes: the macroplankton or "net plankton," so named from the collection with 200-500 micron mesh nets; microplankton, from 60 to 100 microns in diameter; nanoplankton, from 5 to 60 microns; and the even smaller ultraplankton or "centrifuge" plankton. Some of these smaller organisms require electron microscopy techniques for study; relatively little is known about them, although

they may constitute an important fraction of total metabolic activity in the open ocean.

According to Parsons and Takahashi (1973), major classes of phytoplankton are the Cyanophyceae (blue-green algae), Rhodophyceae (red algae), Cryptophyceae, Haptophyceae, Chrysophyceae (yellow algae), Chlorophyceae (green algae), Prasinophyceae, Bacillariophyceae (diatoms), and Dinophyceae (dinoflagellates, some of which are also classed as Protozoa). The latter four classes are most important among marine groups.

Major animal phyla represented in the zooplankton are the Protozoa (Oligotrich and Tintinnid ciliates, Radiolaria and Foraminifera), Coelenterata (Hydrozoa and Scyphozoa), Ctenophora, Chaetognatha (arrow worms), Annelida (polychaete worms), Arthropoda (Crustacea: copepods, cladocerians, mysids, euphausiids, ostracods, cumaceans, amphipods, and isopods), Subphylum Urochordata (salps and appendicularians) and Mollusca (heteropods and pteropods).

Environmental factors such as light, temperature, salinity, and the presence of nutrients influence the abundance and distribution of planktonic species. Some plankters are cosmopolitan, being distributed over a wide geographic range of conditions, while others are stenotopic, and are thus good indicators of certain water masses. Plankton which can survive a wide range of salinities are termed euryhaline as opposed to stenohaline.

The marine community and the abiotic environment in any region are most appropriately considered an ecosystem involving mutual interaction and dependency of all its constituents, and there are a few such studies. However, since quantitative measurement of marine ecological processes often requires isolation of particular activities, the majority of investigations have been confined to specific limited topics, such as photosynthesis or nutrient utilization.

Much current research has concentrated on the description, often by equations derived from quantitative measurement, of specific, limited biological metabolic rate processes. These investigations, at sea or in the laboratory, consistently indicate the need for further research. Therefore, no comprehensive quantitative model of any oceanic ecosystem has yet been constructed, although a few mathematical simulations have been attempted (Vinogradov et al., 1972).

Important general discussions of the biota and their distributions in the Pacific Ocean are those by Bogorov (1969a) and by McGowan (1971). The literature review by McGowan digests the findings of Sverdrup et al. (1942), Ekman (1953), Hedgpeth (1957a) and others in a series of maps and tables of species distributions throughout various water masses, including those in DOMES, and adopts the general principle of water masses as ecosystems. Problems inherent in sampling and obtaining valid quantitative calculations are also discussed. McGowan (1974) also examines general ecological patterns and processes throughout the Pacific, concluding that the warm water cosmopolite species, such as those occurring in DOMES, may be anomalies, not being limited to simple faunal zones, for reasons not yet understood. DOMES appears to fall within a region characterized most accurately as an "open" rather than a "closed" system, in which horizontal influx and outflux of allochthonous individuals and nutrients occur on a large scale. Volkov (1973) observed that the quantitative distribution patterns of 43 plankton species sampled aboard the R/V Tinro, during three cruises (1965-68) within DOMES, were common to the entire Pacific, rather than restricted to a particular water mass.

Over the past decade, a number of significant general investigations of the ecology of the eastern tropical Pacific, to the east of and encompassing DOMES, have been published. Earlier studies by King and Iverson (1962) examined the relationship between tuna trawl catches and zooplankton biomass,

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as well as C^{14} uptake by phytoplankton, noting diel variations. Subsequently, Blackburn (1966a) analyzed chlorophyll a, primary productivity, zooplankton biomass and micronekton biomass within the upper 200 m from the American coast to 130°W, between 40°N and 40°S. Vertical and horizontal distribution, diel and seasonal variation, taxonomic composition of standing crops, and relationships between trophic levels were compiled from a variety of sources. Data concerning the relationship between standing crops at various trophic levels, collected 5°N to 12°N along the 95°W meridian, are probably also applicable DOMES (Blackburn, 1966b). During the 1967-1968 EASTROPAC cruises through DOMES, Blackburn et al. (1970) measured five sets of standing stocks: chlorophyll a from 0-150 m, night and day zooplankton biomass from 0-200 m, night crustaceans, micronekton, and fish/cephalopod micronekton biomass from 0-200 m. These standing stocks declined from east to west, and were higher in upwelling areas than elsewhere.

The mechanisms by which marine ecosystems function are not yet well understood. According to Riley (1962) in his comparative study of three areas of the world ocean (none of them in the Pacific), the structure of the food web appeared to be a function of environmental factors of primarily a physical nature: solar radiation, vertical circulation, the nutrient pool, depth of water, and the character of bottom sediments. Dayton and Hessler (1972) have suggested that in deep-sea communities, at least, consumption by "cropper" or opportunistic species creates a disturbing effect upon what would otherwise be an increasingly simple community of food competitors; this disturbance permits species diversity by interfering with patterns of competition characterized by the Stability-Time Hypothesis (Sanders, 1968).

Using data obtained during the 44th Vityaz cruise throughout the eastern equatorial Pacific, including DOMES, Vinogradov et al. (1972) constructed a mathematical simulation model of the pelagic community within 0-200 m of the

surface, expressing the energy flux in calories. Computations derived from this model correlated with findings in the field.

Similarly, Blackburn (1973) compared, by covariance analysis, simple regressions of various standing stocks on each other and on primary productivity, for various seasons and locations from 100°W to 121°W and from 3°S to 16°N. Transfer of material appeared more efficient in oligotrophic than in eutrophic situations. Interactions between zooplankton and phytoplankton in the eastern tropical Pacific are also described by Longhurst (1976).

Several other investigations are directly relevant to understanding the ecology in DOMES. Brock et al. (1965) produced a baseline faunal study of the waters surrounding Johnston Island, with particular reference to the potential impact of dredging activities there. A similar comprehensive compilation of information was made by Amerson (1973) for Johnston and Sand Islands. Bennett and Schaefer (1960) examined the role of islands and seamounts as agents of change in physical circulation and related biochemical cycles of the food chain at Alijos Rock and in the Revilla Gigedo Islands (Clarion Island, Shimada Bank, and Socorro Island) to the east of DOMES. Recently, Gunderson et al. (1976) investigated biological dynamics as measured by radiant energy transmission, plant nutrients and biomass distributions (phytoplankton, microzooplankton, bacteria, and fungi) at 20°41'N, 156°W. at the northwestern border of DOMES.

PHYTOPLANKTON

WITHIN DOMES

The phytoplankton, including diatoms and other algae, are the major primary producers which biosynthesize organic material. One important source of information of such productivity, its measurement, and distribution of species,

is the Proceedings of the Conference on Primary Productivity Measurement, held at the University of Hawaii, August 21-September 6, 1961, and edited by Maxwell S. Doty (1961). This volume contains contributions by Holmes, Koblents-Mishke, Allen, Humphrey, Thomas, Cassie, Strickland, and other investigators. The research compiled in the Proceedings and cited below is not confined to DOMES, but includes that area or some portion of it.

Data summaries by Holmes include physical, chemical and biological observations taken from Vityaz cruise 29, and the Inter-American Tropical Tuna Commission. This information is presented in extensive tabular form (Holmes, 1961).

Similarly, Allen compiled and tabulated phytoplankton species lists by region, on conclusion recommending two groups of species for further investigation: (1) cosmopolites such as Thalassiothrix longissima, Rhizosolenia alata, and Ceratium tripos, which appear to develop over a wide range of temperatures, salinities and nutrient conditions; and (2) those which occur only within a limited range of hydrographic conditions and in specific water masses (Allen, 1961).

The Proceedings also contain an extensive annotated bibliography of primary productivity studies, most of which pertain to trophic-dynamic principles and methodologies of investigation, rather than to regions within or adjacent to DOMES. In addition, El-Sayed (1970) has compiled and mapped available data on the standing crop of phytoplankton, expressed as distribution of chlorophyll a, throughout much of the Pacific Ocean.

One of the earlier investigations of the amount of phytoplankton in DOMES sampled organisms from three stations situated in the South Equatorial Current. Hasle (1959) found a fertile zone lying from 10°S to 10°N, with a higher concentration of phosphates near the equator and a correspondingly greater abundance of phytoplankton, both of which diminished poleward at higher latitude.

It was suggested that this phenomenon was the result of meridional transport of upwelled water originating farther south.

Vertical distribution within the upper 50-100 m showed a decrease in number of cells with increase in depth; some coccolithophorids were exceptions to this trend, possibly as a function of species-specific variations in light requirements. Hasle's list of observed phytoplankters includes 48 species of Bacillariophyceae (diatoms), 57 species of Dinophyceae, 33 coccolithophorids, 9 other flagellates, and 20 types of ciliates. A pennate diatom species, athecate dinoflagellates, and certain small coccolithophorids were most commonly observed. Concentration techniques were employed to yield estimates of cell abundances and number of species. A summary of her recent work on biogeography of marine planktonic diatoms (several species from within DOMES) is given in Hasle (1976).

The 34th Vityaz expedition, September to December, 1961, studied the occurrence and distribution of diatoms in the plankton of the equatorial Pacific along the four meridional sections 160°E and 176°W, 154°W, and 140°W. They recorded 97 planktonic diatoms, grouped for investigation purposes into three distinct patterns of geographic distribution (Belyayeva, 1970). Species representative of each group were mapped by station. Group I, in the eastern part of the region, yielded patterns largely corresponding to the general distribution of the phytoplankton crop: greater concentration occurred most frequently at 140°W and 154°W, where the highest phosphate concentration and upwelling occur. Group II, in the western part of the region, contained certain species found most frequently at 160°E and 176°W. These appeared to thrive in waters with a lower concentration of nutrients. It was suggested that this observation was the result of lower nutrient requirements by these species, which reach their population maxima under conditions adverse to the growth of organisms requiring higher nutrient concentration, and in fact may be

suppressed in eutrophic locations by the massive development of species thriving there. Finally, individual species composing Group III, showing no preference for either type of location, may grow equally well in waters either rich or poor in nutrients. For these species, the often axiomatic connection between phosphate concentration and abundance of phytoplankton was not established.

Desroisières (1969), in a general survey of phytoplankton distribution, collected in 80 μ mesh net, observed an increase in temperature, with decreasing phosphate and nitrate content of the surface water from east to west, south of DOMES along the equator, and a concurrent decrease in phytoplankton abundance. A list of species is also given.

Some organisms appear to be specifically dependent on phosphate. Belyayeva (1971), while mapping the distribution of diatoms in tropical regions west of 160°W longitude, encountered two groups of algae whose quantitative distribution was associated with presence of phosphate.

During the fall, 1969, cruise of the R/V Hakuho Maru, the vertical and horizontal distribution of coccolithophorids was observed in a north-south transect passing through DOMES (Okada and Honjo, 1973). Samples obtained from the entire water column down to 5000 m were compared with the upper 200 m. In a subsequent study, Honjo and Okada (1974) computed cell number per unit volume of water, and reported these findings as characteristic of specific floral zones and assemblages. Mapping of the diversity indices of 90 species revealed a vertical and horizontal variation in the photic zone profile; the percent similarity index was computed to compare horizontal and vertical groupings within specific depth levels or at individual stations.

Marumo et al. (1971) investigated the nanoplankton community in surface microlayers, finding concentrations of diatoms as high as $10^4/1$ in the surface films, but only 50 to 200/1 in lower layers; however, of the film organisms,

half were dead or damaged by the effects of solar radiation, indicating that abundance in the film is formed by physical accumulation rather than by propagation and growth.

Forsbergh and Joseph (1964) used data obtained aboard the R/V Esmerelda during 1962 to investigate the geographical distribution of the standing crop and productivity of phytoplankton at the surface of the eastern Pacific, east of 130°W and between 10°N and 33°S. They discussed general relationships among the thermocline, topography, nutrient concentrations, and various trophic levels.

In certain regions, including the eastern portion of DOMES, nanoplankton are often responsible for 80%-99% of observed productivity (Malone, 1971a). Net plankton fractions are greater in neritic than in oceanic waters, suggesting that grazing pressure selects against larger phytoplankters. Net plankton and nanoplankton exhibit different diurnal rhythms within tropical oligotrophic waters, wherein both sizes appear to be nitrogen-limited. Net plankton assimilation rates reached a maximum in the afternoon, while nanoplankton values were greatest in the morning; however, in eutrophic surface waters, nanoplankton also exhibited an afternoon maximum (Malone, 1971b).

Within any particular species, size appears to be in some degree a function of vertical water movement. Semina (1968, 1971, 1972) found that smaller cells occur mostly where there is a downward flow, or convergence, while larger cells exist in greater abundance within an upward flow, or divergence. Along the 174°W longitude, from 40°S to 30°N, the number of phytoplankton species with cells less than 60 microns in diameter far exceed larger species, and those of 20 microns or less occur in greatest abundance. Larger cells existed in relatively greater abundance near the equator (Semina, 1969). Basic patterns of cell size distribution appear related not only to vertical water movement,

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but to the value of the density gradient in the main pycnocline, and also to phosphate concentration (Semina, 1972).

Size differences in the diatom, Anellus californicus, taken from Miocene deep-sea sediments at two stations within DOMES, have been studied in comparison with samples of the same species obtained near Honshu, Japan (Burckle and Todd, 1974) with an aim toward a better understanding of the causes of such variations.

Using samples taken during the fall, 1969, Hakuho Maru cruise, Marumo and Asaoka (1974) studied vertical and latitudinal distribution (155°W, 50°N to 15°S) of blue-green algae, primarily a Trichodesmium red tide, which constitutes an important part of plankton communities. T. thiebautii was found ubiquitously distributed in the lower 100-200 m layer in water warmer than 20°C, with few nitrates, nitrites or diatoms, but in the presence of ammonium and phosphate.

A fairly extensive literature exists dealing with the primary production rates and the metabolic processes of planktonic organisms in the northeast central Pacific, including the DOMES region or portions of it. Most research of this type has been conducted over the past two decades and makes use of the C^{14} isotope as a quantitative tracer, a technique devised by Steemann Nielsen. This technique has been evaluated methodologically, and its error-components computed (Cassie, 1962). It remains the single most important analytical tool for primary productivity measurement (Steemann Nielsen, 1951, 1952).

Using data collected during the 1958-59 Vityaz cruise, Koblents-Mishke (1961; Koblents-Mishke et al., 1968) studied phytoplankton populations and primary production, obtaining curves for the dependence of photosynthesis upon available light energy. These studies concluded that in 13% to 52% of observed cases phytoplankton experience light limitation in tropical regions, as the result of the discontinuity layer. Productivity of less than $0.1 \text{ mg/m}^3 \text{C/day}$

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in some regions was low compared to regions of upwelling, probably due to the enriched nutrients in these areas.

Samples collected from stations in DOMES and subjected to laboratory experiments showed evidence for a daily periodicity in photosynthesis (Doty and Oguri, 1957). Maximum photosynthetic ability appeared during the few hours before midday, with the minimum around 1900 hours, as determined by the C^{14} "light-dark bottle" technique. Samples were taken from the sea surface, and findings were believed representative of in situ productivity. Measurements made of photosynthetic activity and chlorophyll a content, taken over a 46-hour period from surface waters near Clarion Island in the Revilla Gigedo Islands, corroborated observations of diurnal periodicity (Shimada, 1958). Holmes (1958) summarized available data from TRANSPAC, Eastropic and Scope cruises, to present a comprehensive picture of surface chlorophyll a and primary productivity. Observed photosynthetic rates per unit of chlorophyll a were compared in this study with laboratory investigations. Shimada (1958) found a positive correlation between photosynthetic rates and chlorophyll a concentration.

The vertical distribution of chlorophyll a in the northeast Pacific ($45^{\circ}10'N$, $126^{\circ}56'W$) shows a subsurface maximum (Anderson, 1969). Other investigations have also indicated such a relationship. During the fall, 1969, cruise of the R/V Hakaho Maru, high concentrations of chlorophyll a were observed along longitude $155^{\circ}W$ between $50^{\circ}N$ and $15^{\circ}S$ at depths of 150 m. Within the DOMES area, maximal chlorophyll a accumulations centered at a depth of 70 m and ranged vertically between 10-150 m, within the euphotic zone. These concentrations were compared with photosynthetic rates (Takahashi et al., 1972). Similarly, Venrick et al. (1973) compiled results of data collected on several expeditions north of DOMES and suggested the occurrence of a deep maximum of chlorophyll a and phytoplankton concentration between 50-100 m

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below the surface as a widespread phenomenon in the open sea. Earlier, Humphrey (1970) examined concentrations of chlorophyll a and c over a large area of the Pacific, including a few sections in the southeastern portion of DOMES. From data collected from 1958 to 1967, curves were plotted at station locations for both pigments, indicating summer and winter depth maxima for each.

Such seasonal effects were noted by Owen and Zeitzschel (1970), and although their conclusions were derived from data taken during the 1967-1968 EASTROPAC expedition, centered east of DOMES, they regarded these fluctuations as common to areas west of their stations. A production maximum occurs in early boreal spring and a minimum in autumn, in a seasonal cycle resulting from temporal variations in thermocline topography and nutrient supply.

Using primary production data obtained during the 43rd Vityaz cruise measured by C^{14} techniques, Sorokin (1970b) studied the effect of nutrient enrichment from islands, including Fanning Island, upon productivity. Measurement of the factor K_p indicated that maximum growth of phytoplankton occurs above the thermocline at a depth of 40-60 m. Profiles taken near Fanning Island to determine productivity in the surface layer showed the zone of enrichment to be only 2-4 miles; thus, the enriching effect of this atoll is very limited horizontally, and probably has little impact upon the level of productivity of the main masses of oligotrophic water in the area. However, Gordon et al. (1971) reported that in Fanning Lagoon the standing crop of phytoplankton, composed primarily of dinoflagellates, diatoms and coccoid blue-greens, was 12.6×10^4 cells/l and the productivity $9.29 \text{ mgC/m}^3/\text{hr}$, with chlorophyll a averaging $0.55 \text{ } \mu\text{g/l}$. These values are higher than those of other Pacific atolls, and are possibly the result of greater availability of nutrients, due to the island's unique geographic features.

The island systems within the DOMES area may exhibit unique characteristics including those of species distribution. Fournier (1970) reported the occurrence of six species of coccolithophorids at various locations around Fanning Island and at English Harbor, where falling tides eject a plume of lagoon water. Within the plume, diatoms appeared most abundant, but at other locations coccolithophorids were the dominant phytoplankton.

NEARBY DOMES

Most of the research conducted on the relationship between nutrients and primary productivity, notably that dealing with nitrogen and phosphorus, has only skirted the DOMES area, but is relevant to its ecology and for that reason is included here. The majority of work in this area was done by Thomas, individually and in association with others. One such paper summarizes data on surface nitrogenous nutrients obtained during STOR cruises from 1959 to 1962, and tests the hypothesis that nutrients other than phosphates limit phytoplankton growth. Three phytoplankton cultures exhibited growth in vitro within a medium limited by low nitrate concentration, but containing ammonium and various amino compounds, yielding information as to the relative importance of nitrate and ammonium as nutrient sources (Thomas, 1966b).

In experiments conducted off Baja California and including some stations located within the eastern region of DOMES, Thomas (1969) measured C^{14} uptake and chlorophyll increase in samples enriched with various nitrogenous nutrients singly and as mixtures, with trace minerals and nonnitrogenous nutrients as controls. Results in these experiments agreed with his earlier study except in nutrient-rich regions of upwelling. In such localities, grazing or sinking processes apparently act more importantly as population controls.

Rates of uptake of nitrate or ammonium ions by marine phytoplankton may be described by the Michaelis-Menten kinetic equation, as discussed by Caperon (1967), Dugdale (1967), and Eppley and Thomas (1969):

$$v = \frac{V_m S}{K_s + S}$$

Thomas (1970a) employs a form of this equation in nutrient enrichment experiments. Assimilation ratios and dark uptake of CO_2 by phytoplankton in nutrient-poor water did not vary greatly from values derived from the same parameters in algae from nutrient-rich water. Apparently, adequate ammonium ion and amino nitrogen exist in nutrient-poor waters in sufficient rates of supply to maintain the algae in healthy condition. Subsequent experiments were done to evaluate the quantitative requirements for nitrogen by phytoplankton (Thomas, 1970b). Thomas et al. (1971) described the magnitude of organic nitrogen in an area from the American coast west to 119°W , and from 20°N to 10°S , using 94 samples obtained during the second EASTROPAC Survey (August-September, 1967), concluding that nitrogen deficiency in poor waters is not alleviated by compounds other than ammonium and amino-nitrogen.

Cells of the diatom Chaetoceros gracilis, grown in nitrogen limitation, demonstrated a variety of relationships between growth rate, cell size, and photosynthesis, as well as between ratios of carbon and nitrogen, and carotenoid to chlorophyll (Thomas and Dodson, 1972). These findings, while not derived from conditions in situ, are presented in an attempt to elucidate relationships occurring under natural conditions.

The investigations of Goering et al. (1970) discovered a pronounced discontinuity layer existing within the euphotic zone in which phytoplankton use nitrate as their chief source of nitrogen, whereas organisms in the overlying nutrient-poor water use the ammonium ion as a nitrogen source. Chlorophyll

a concentration generally increased with depth, reaching a maximum at the discontinuity layer. The half-saturation constant, Michaelis-Menten K, appears to be species-specific, and is influenced by variations in temperature.

The process of nutrient cycling has been studied within the subtropical central gyre of the North Pacific. Investigators measured rates of assimilation of carbon, nitrate, ammonium ion and urea-nitrogen by phytoplankton. Growth rate was estimated at 0.2-0.3 doublings day⁻¹ in the 70-80 m mixed layer, apparently limited by concentration levels of both nitrogen and phosphorus (Eppley et al., 1973). Physiological differences, differences in the ratios of carbon to chlorophyll a and of carbon to nitrogen were noted between phytoplankton in the mixed layer and below the thermocline. These dynamics, occurring 15°N to 20°N, may be a product of the gyre and unique to that segment of DOMES. Rates of excretion of phosphates, ammonium and urea-nitrogen by zooplankton were also measured. Perry (1974, 1976) continued these measurements in oligotrophic waters and laboratory studies, to determine the role of phosphorus as a control of growth rate.

ZOOPLANKTON

A fairly extensive literature deals with the zooplankton of areas including DOMES. Many of these studies are general investigations of biogeography and vertical distribution of the zooplanktonic biomass, while some research deals with specific groups of organisms.

BIOMASS

Zooplankton volumes in the upper 150 m of the Pacific Ocean were mapped by Reid (1962). Calculations of the zooplanktonic biomass made by Bogorov et al. (1968) from samples obtained during the 1957-1959 IGY cruise of the

Vityaz indicate a range of $<25 \text{ mg/m}^3$ to $>500 \text{ mg/m}^3$ within DOMES. Bogorov et al. (1968; Bogorov, 1969b) calculated the total zooplanktonic biomass throughout the surface layers of the Pacific at about 5 billion tons.

The biomass of microzooplankton in the upper 200 m was calculated by Beers and Stewart (1971) from samples taken on the EASTROPAC Cruise 76 aboard the R/V David Starr Jordan (February-April, 1968) at stations along the 105°W meridian, from 10°N to 12°S , somewhat east of the DOMES area. Average microzooplankton volume over the euphotic zone ranged from $15 \text{ mm}^3/\text{m}^3$ to $47 \text{ mm}^3/\text{m}^3$, with taxonomic composition similar to that described for California Current populations.

Four cruises of the R/V Hugh M. Smith, during 1950 and 1951, traversed through the DOMES region, making quantitative oblique hauls to 200 m. Composition of these collections was remarkably uniform, averaging in percent by numbers 57% copepods, 12% chaetognaths, 6% tunicates, 5% euphausiids, 4% siphonophores, and 4% foraminiferans (King and Demond, 1953). Day and night hauls differed between cruises, and between latitudes, but not between longitudes, with the greatest abundance occurring in the region of the equator up to 6°N . This abundance was correlated with inorganic phosphate, oxygen, temperature, and thermocline depth, factors which are influenced by upwelling in the equatorial divergence, and consequent replenishment of nutrients in the euphotic zone. These data have been compiled along with those of six other Hugh M. Smith cruises through 1952, and tabulated as to locational and seasonal fluctuations in abundance (King, 1954).

Subsequent research aboard the same vessel involved 30 stations at which samples were taken at three depths: the surface, the level of the 70°F isotherm, and at 200 m. Night sample volumes exceeded day values at the surface, with night volumes being slightly larger at the intermediate and deep levels. Organism size increased with depth. Copepods were the most abundant group,

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followed by foraminiferans, eggs, tunicates, gastropods, chaetognaths, radiolarians, crustacean larvae, ostracods, euphausiids, siphonophores, and amphipods in that order. Taxonomic composition appeared similar in the North Equatorial Current and the South Equatorial Current. Surface samples were considerably larger in volume and number of organisms than were those from below the surface, and there was no evidence of concentration in the region of the thermocline (Hida and King, 1955).

Later cruises of the R/V Hugh M. Smith resulted in the accumulation of data on plankton density in relation to temperature, thermocline depth, surface inorganic phosphate, and surface salinity. While most of the material was obtained from the Hawaiian Islands, the cruises extended into the DOMES area, and investigators tabulated plankton volume by location, date, and time of sample collection (King and Hida, 1954, 1957).

Diel variations in zooplankton volumes were examined in samples from 21°N, 158°W, just north of DOMES (Shomura and Nakamura, 1969). Correlations were found between volumes of zooplankton and salinities, as well as volumes of zooplankton and depth to the top of the thermocline.

Examining 85 plankton samples collected during the 34th Vityaz cruise, Voronina (1964) noted a quantitative distribution which was species-specific, and attributed it to biotic factors such as different intensities of reproduction, as well as interspecies competition. Copepods were found to be the most abundant group in tropical waters, whereas ostracods form a larger portion of the biomass in central waters (Heinrich, 1968). Heinrich (1969) describes the distribution of 35 zooplankton species, primarily copepods, along the 174°W longitude and the 180° meridian, grouping these organisms into three distinct habitat patterns, corresponding to general biogeographical boundaries.

VERTICAL DISTRIBUTION

The most important work on the vertical distribution of zooplankton in the Pacific, including DOMES, is that of Vinogradov (1970), who compiled data from various cruises of the R/V Vityaz in tropical regions, the R/V Ob in subtropical waters, and other sources. Hundreds of samples were taken from throughout the water column down to 10500 m. Although taxonomic analysis is incomplete, findings indicate that taxonomic distribution is directly related to food resources, and not dependent on local conditions (biotic or abiotic). Phytophages are abundant at 200-750 m where more phytoplankton are available as a food source. Below 750 m, carnivorous zooplankton and detritus feeders predominate. At depths of 2500-3500 m, food resources and the planktonic biomass decrease sharply. The quantitative vertical distribution of zooplankton is generally the same throughout the ocean. Vertical migration, as well as vertical mobility of the biotope (the water itself), tend to obscure definite faunal boundaries. However, in tropical regions the population of the upper 200 m appears relatively more stratified than elsewhere.

Legand et al. (1972) investigated the vertical distribution of zooplankton during cruises of the R/V Coriolis along the equator from 130°W-180°W. Organisms were sampled by day and at night, at depths of 70 m, 130 m, 270 m, 550 m, 880 m, and 1100 m. These were classified as belonging to either a "superficial" (to 450 m) or a "deep" system, the latter deriving most of its energy from the former.

Little research has been done relating zooplankton to the oxygen minimum in or nearby DOMES. In the southern end of the California Current, Longhurst (1967a) has studied the vertical distribution of zooplankton, primarily copepods, in relation to the oxygen minimum, which extends just below the shallow thermocline, to about 1000 m, and within 150-500 m range, and contains generally

less than 0.2 ml/l of dissolved oxygen. "Resting" copepods, Calanus helgolandicus, were generally found below 150 m. Several species migrated at night upward into the euphotic zone of the California Current, which with its rich nutrient supply is believed responsible for the relative abundance of fauna in this particular oxygen minimum as compared with other minima. In this same region the diversity and trophic structure of zooplankton communities was described by Longhurst (1967b).

PROCESSES

Metabolism and production of zooplankton were investigated by Shuskina and Pavlova (1973) during the 44th and 50th Vityaz cruises in the equatorial Western Pacific. Oxygen consumption rate in relation to body weight was measured and regression equations for these were determined for animals of 13 taxonomic groups. Average metabolism rates were determined for 34 taxonomic groups of pelagic animals. Relations between the production rate and body dimensions of 15 taxonomic groups of pelagic animals were derived from these data, and the findings plotted and tabulated, with an aim towards determining food requirements and describing the energy flow in a tropical plankton community.

SPECIFIC GROUPS OF ORGANISMS

The majority of recent zooplankton research has dealt with specific groups of organisms, rather than with the entire zooplanktonic fauna. Many of these species are large, and may be classified either as macrozooplankton or as micronekton. Most of the literature treats them as zooplankters, rather than as nekton, a classification system followed here.

Typical of such groups are the crustaceans, including the euphausiids and copepods, the most abundant groups within the tropics, amphipods, as well

as the chaetognaths, and also the larval stages of larger, nektonic decapod crustaceans.

A systematic study of calanoid copepods from equatorial waters was undertaken aboard the R/V Hugh M. Smith, with supplementary data obtained from the R/V Stranger (Grice, 1961). One of the 14 stations from which samples were taken lies within DOMES, and several others lie along the equator. One hundred and ten species, belonging to 18 families, were recorded by station location. The bibliography includes literature describing these families throughout the world ocean.

Sherman (1963) studied the distribution of pontellid copepods within surface water types, the North Pacific Central (NPC) and North Pacific Equatorial (NPE), as well as the California Current Extension, a zone of intermediate salinity between them. The NPE water occupies DOMES from its eastern edge to about 155°W. The California Current Extension intrudes from the region north of DOMES at 155°W to 170°W, flowing into the Equatorial Counter Current at about 10°N, which in turn moves westward with the counterclockwise gyre of the NPE water. The NPC water mass cycles clockwise from about 170°W to 130°E, through the northeastern portion of DOMES, and is bounded by the Equatorial Current. Thus, DOMES contains two regions of conversely directed currents interfaced by the intermediate California Current Extension; each is a unique water type, for which species distribution patterns may serve as indicators.

Sherman's study indicated that Labidocera acutifrons, immature L. sp., and L. detruncata were associated with the NPC water type, at least during the summer months. These animals were found to be more widely distributed within the intermediate zone and the NPE water, a seasonal variation believed related to a seasonal shift in water type distribution. Depth and sampling time appeared important factors: collections made at 2100 hours at the sur-

face and from 0-60 m showed more abundance in surface waters than in lower levels at this hour. Data relating distribution of each species to surface water type, salinity and temperature by day and night are plotted and tabulated. Subsequent research in the central south Pacific (Sherman, 1964) included some DOMES data for comparison.

In a comprehensive study of worldwide distribution of the calanoid copepod genus, Clausocalanus, Frost and Fleminger (1968) compiled collection information from a variety of international sources, with an aim toward revising the taxonomy of the genus. A few of the cruises traversed through DOMES. Mullin (1969) investigated the geographical and vertical distribution, the morphology, and the seasonal biology of species of planktonic copepods.

Vinogradov and Arashkevich (1969) examined the vertical distribution of the numbers and biomass of the upper zonal copepods, Calanus cristatus, C. plumchrus, Eucalanus bungii, Metridia ochotensis and M. pacifica, species that comprise about 55% of the biomass in the 0-4000 m layer of the boreal northwestern Pacific. Ninety percent of the population of C. cristatus inhabit depths above 3000 m, and the other species above 750-1000 m, with juveniles feeding in the surface euphotic zone and descending as adolescents into deep water. Thus, the interzonal species form a link between surface and deep-water communities, for which they serve as a food reserve.

Arashkevich (1972) has calculated the biomass and vertical distribution of copepod groups in the tropical Pacific, including a station at 5°N, 176°E, to the east of DOMES.

The surface pontellid copepods of the 0-10 cm and 20-30 cm layers were sampled at five stations along the 145°W longitude, two of which lie within DOMES, and another within 7° south of DOMES (Hensler, 1970). Two faunal zones were found, the upper stratum characterized by diurnal abundance of

pontellids, and the lower by a high proportion of immature calanoid species. The number of animals in both layers increased at night. No species variations among the pontellids appeared across the equatorial current system, along that single longitude. In his work on the genus Eucalanus, Fleminger (1973) listed the calanoid copepod, Eucalanus attenuatus, as having been found in DOMES.

Gueredrat (1971) sampled copepods along the equator from 86°W to 151°E, traversing areas of varying or mixed water types, and discovered distributional differences related to currents, vertical circulation, physicochemical sea water properties and distribution of the phytoplanktonic food source. A similar study was subsequently made along the equator from 90°W to 16°E (Gueredrat, 1974). Gueredrat et al. (1972) aboard the R/V Coriolis traversing the equator from the Galapagos Islands to 160°E, tabulated the number of individual copepods and euphausiid species at all stations. Euphausiids included Thysanopoda tricuspidata, T. monacantha, T. aequalis, T. pectinata, T. cristata, T. orientalis, Nematobranchion flexipes, N. boopis, Nematoscelis microps, N. gracilis, N. tenella, Stylocheiron elongatum, S. maximum, S. abbreviatum, Euphausia diomedae, E. paragibba, E. eximia, and E. gibboides. The following copepods were found: Pleuromamma xiphias, P. abdominalis, P. quadrangulata, Eucalanus subtenuis, E. subcrassus, E. attenuatus, E. elongatus, Rhincalanus cornutus, R. nasutus, Euchaeta marina, E. media, E. concinna, and Undeuchaeta plumosa.

In a global-scale genus revision study on the systematics and distribution of four Pontellina species, Fleminger and Hulseman (1974) found that geographic distribution was related to major near-surface hydrographic features, particularly the occurrence of eutrophic and oligotrophic areas. Data from the EQUAPAC-Stranger and EASTROPAC-Argo cruises passing through DOMES are included in this extensive report.

Data collected during the EASTROPAC expeditions (which entered the farthest east regions of DOMES) indicated that Evadne, a cladoceran, is also an epiplankter of very shallow distribution, occurring primarily in surface samples, not deeper than 10 m, with certain species showing a preference for warmer or cooler water (Longhurst and Seibert, 1972).

Bowman (1953) investigated the systematics and distribution of the pelagic amphipod families, Vibiliidae, Paraphronimidae, Hyperiididae, Dairellidae and Phrosinidae, in waters off the American coast (including 30 stations within DOMES) and described 9 new species, Hyperoche laticarpus, H. shoemakeri, H. lighti, H. stebbingi, H. stepheuseni, H. parviceps, Themistella johnsoni, Euprimno rectimanus, and E. abyssalis.

The geographical distribution of 27 species of chaetognaths (Bieri, 1957, 1959) fit the pattern of faunal provinces described by Ekman (1953) and established several subdivisions within the warm-water province extending 40 degrees north and south of the equator. Each of these regional subdivisions may be characterized by distribution patterns of chaetognath species, but also contains four warm-water cosmopolites--Sagitta enflata, S. hexaptera, S. pacifica and Pterosagitta draco.

Chaetognath species as indicators of water type were collected and analyzed during the 1955 EASTROPAC expedition, resulting in a refinement of species identification (Sund, 1959). Alvarino (1964) compiled composite data from a variety of Scripps Institution of Oceanography research expeditions to produce a comprehensive worldwide pattern of the bathymetric distribution of more than 30 chaetognath species. These were grouped into epiplanktonic, mesoplanktonic and bathyplanktonic categories, and presented in tabular form by depth and region. The tropical region contained 15 species inhabiting the upper 150 m, 2 from 300-600 m, and 8 below 600 m. Some tropical samples were

obtained from stations within DOMES; however, since other samples were taken from southern latitudes, the findings may only be applicable to the cosmopolite species. Vertical migrations related to light, temperature, seasonal changes, and food supply were reported in the upper, epiplanktonic stratum.

During the 44th Vityaz cruise, Kolosova (1972) examined patterns of vertical distribution and daily migration of several chaetognath species, including S. enflata, S. hexaptera, and Pterosagitta draco. Although her research was conducted at a station outside DOMES, her findings are probably representative of the behavior of these cosmopolite species in other warm-water regions. A typical species, S. enflata, exhibited vertical migration rising from around 51 m to 29 m at night, then sinking to its original depth toward midday. Temperature appeared to be the most important factor influencing this migration.

The euphausiids comprise another important group of macrozooplanktonic crustaceans. Brinton (1962a) compiled quantitative data derived from samples obtained from several cruises north of DOMES, including material taken aboard the R/V Stranger during the 1956 EQUAPAC cruise through the mid-equatorial Pacific. Environmental variables such as temperature, current and latitude, and seasonal variations in sunlight intensity, water transparency, and amount of food or oxygen in the water, were all shown to have an effect upon the horizontal and vertical distribution of species and their cycles of breeding and growth.

In a subsequent study, Brinton (1962b) described the distribution of 59 euphausiid species throughout the Pacific, based upon ocean surveys carried out from 1959 to 1961 by Scripps Institution and others. Two of the stations included in this survey lie within DOMES. Vertical and horizontal distributions are presented, in which the tropical Pacific is treated as a single faunal region. Day and night vertical distributions indicate that nearly all Pacific euphausiids are concentrated at shallower depths during the day than

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at night. Two bathypelagic genera inhabit depths greater than 1500 m; however, 6 of the 10 genera were mesopelagic, living from 500-1000 m, while the remaining two were epipelagic.

Ponomareva (1966) compiled data on the distribution of euphausiids throughout the Pacific, including Brinton's findings in a chart of the distribution of specimens per 1000 m³ for the layer between the surface and 100 m. The biology of the euphausiid Nematoscelis was studied by Gopalakrishnan (1973).

The most comprehensive research on euphausiids in tropical waters was that done by Roger (1967a, 1967b, 1968, 1971a, 1971b, 1973a-f and 1975). Using samples obtained from cruises along the equator between 92°W and 162°E, Roger examined the geographical distribution (Roger, 1967a, 1967b, 1968) and the vertical distribution (Roger, 1971a, 1971b) of all observed tropical species. In an extensive six-part survey (Roger, 1973a-f), the trophic dynamics of the euphausiids as a group were investigated, and findings presented. The role of euphausiids in the food chain is defined through analysis of their nutrition, vertical distribution and migrations, and utilization by pelagic predators. These findings indicate that euphausiids, because of their migration patterns from epipelagic to mesopelagic levels, may be a main factor in determining the structure of food webs. Feeding and migration patterns appeared to be genus-specific. Daily vertical migration appears to be inefficient for the transfer of energy; however, the process apparently fulfills other functions, such as transport of the biomass throughout the water column (Roger, 1975).

During the 1953 EQUAPAC-Stranger cruise through DOMES between 165°-175°W and 6°S-10°N, the larval and developmental stages of Thysanopoda tricuspidata were obtained and identified (Knight, 1973).

Other important zooplanktonic species include the little-studied Euthecosomata, a holopelagic mollusc of the north Pacific, which may possibly occur

in DOMES, since this organism exhibits some of the distributional characteristics of the chaetognaths and euphausiids (McGowan, 1960).

Bradshaw (1957) grouped the distribution patterns of 27 species of living planktonic Foraminifera of the Pacific into faunal zones. He noted that tropical specimens exhibit relatively large size and a high reproductive rate. A similar study by Banerji et al. (1971) grouped the Pacific species by water mass types, and established a weak relationship between temperature/salinity and the abundance and species diversity of 39 pelagic planktonic Foraminifera. Further studies of Foraminifera are discussed under "Benthos" rather than here, because, while many of these organisms are planktonic while alive, they die, sink, and leave exoskeletons in the benthos. Other Foraminifera are benthic, and both dead and living specimens are found in sediments for these species.

A final group consists of the larval stages of fauna which are nektonic or benthic in adulthood, but which go through meroplanktonic stages of development. Little literature exists dealing with this subject, and none is confined to DOMES, or to adjacent regions. The studies cited below present data of general interest which may be applicable to the biota of DOMES.

Scheltema (1968) discusses the dispersal function of planktonic larval stages, which enable species to breach faunal barriers and colonize new regions. These larvae are dispersed throughout great distances by ocean currents. The gastropod Philippia of the Hawaiian Islands emerges from its larval stage, which varies in duration, only upon contact with its sole food source (Robertson et al., 1970). Thus, the larval stage permits such animals to delay maturity until they encounter an environment conducive to their particular requirements.

Mileikovsky (1971) has described the planktonic larval stages of marine bottom invertebrates as well as other fauna, drawing upon material from the world ocean. He points out the limitations of the three major groupings of

marine life--into surface (upper layer, and including pleuston and neuston), pelagic (planktonic and nektonic) and benthic--noting that these divisions are based upon adult stages of life (Mileikovsky, 1972). His work proposes the category "pelagic larval," which cross-cuts the others. Within this category exist three subgroups: larvae which undergo their entire development in an environment different from that of their parents, such as the pelagic larvae of bottom invertebrates which develop in the plankton, neuston, or pleuston; larvae developing in the same general pelagic environment, but in "non-parental" ecological groups, such as larvae of nektonic species developing in the plankton; and larvae developing within the same environment, such as pleustonic species in the pleuston. The first of these subcategories would include larvae of the decapods, such as Scyllarides and Panulirus. Larval stages of Panulirus and Stomatopoda have been studied by Michel (1970, 1971) in tropical regions including DOMES, from the equator to 10°N and between 90°W and 160°E. Johnson (1970) made a similar study of Scyllarides near the Galapagos Islands, east of DOMES.

PLEUSTON

PLEUSTON AND NEUSTON

An important group of marine organisms is that associated with the surface of the ocean. Animals dwelling on the surface face unique problems of adaptation to changes in temperature, wind, and salinity (reduced after a heavy rain), high concentrations of surface-active organic matter, and solar radiation. The term "pleuston" was originally used by freshwater biologists to describe microscopic plants and animals living in or on the surface film. Soviet scientists have restricted the definition of "pleuston" to animals passively floating at the sea-air interface, water surface, or uppermost water layer, and especially adapted to existence there, such as Velella velella, Physalia utriculus, and Porpita. Western biologists commonly include the

pleuston within the neuston, a broader category including fish eggs and larvae. Discussion of terminologies used to describe surface organisms has been presented by David (1967), Zaitzev (1971), and Hempel and Weikert (1972).

A significant recent contribution to the study of marine neuston is that of Zaitzev (1971) who also reviewed much of the extant literature on the subject. Zaitzev's work deals with the world ocean and contains no data specific to DOMES. Savilov (1970) presented a review of most recent studies and also compiled extensive information concerning Pacific pleuston during various cruises of the R/V Vityaz between 1955 and 1961, including approximately 50 stations in DOMES. Pleuston comprise a unified faunal complex consisting of three major ecological groups: (1) typical forms spending much of their life cycles at the ocean surface, such as Physalia, Velella, Porpita (Coelenterata), Iathina and Glaucus (Gastropoda) and Halobates (Insecta); (2) commensals and symbionts including certain turbellarian worms, Planes (Decapoda), Idothea (Isopoda), Fiona (Nudibranchiata), Lepas (Cirripedia), juvenile penaeid shrimp, and the algae, zooxanthellae; (3) temporary components of the pleuston community consisting primarily of the larvae of otherwise benthic species, fish eggs and larvae, and polychaetes. Distribution patterns of some of these organisms are mapped throughout the Pacific, including DOMES. Savilov estimated that the world ocean contains about 100 species of pleuston, belonging primarily to the orders Siphonophora, Chondrophora, Actiniaria, Turbellaria, Gastropoda, Cephalopoda, Polychaeta, Isopoda, Decapoda, Cirripedia, Copepoda, Insecta, and Pisces.

Cheng (1975) has adopted Savilov's three ecological categories. In a detailed literature review of studies of marine pleuston, she includes locality records of species in the Pacific including DOMES, but notes that information about marine pleuston, other than habitat description and taxonomy, is sparse.

INSECTS

Only one genus of oceanic marine insect is known to exist: Halobates, consisting of 39 observed species. Seven of these exist only on the open ocean at great distances from land, living in the epineustonic layer on the surface of the water, a stratum unoccupied by any other known marine animal. Most of the recent research on Halobates has been conducted by Savilov (1967) aboard the Vityaz, and by Cheng (1973, 1974). In a general discussion of this little-understood insect, Cheng (1973) compiled data on its distribution, indicating that H. micans, H. sericeus, and H. germanus inhabit DOMES. Temperature, currents and winds apparently influence species distribution, since Halobates is wingless.

Halobates lays its eggs on available floating objects, such as wood pieces, dropped seabird feathers, or tar lumps. It feeds upon zooplankton, and is in turn preyed upon by noddies, petrels, and terns, and probably by some species of fish (Cheng, 1974). Very little else is known of its natural history or trophic-dynamics.

During the 1960-61 voyage of the Monsoon Expedition, which passed by Howland Island and the Line Islands, 154 air-born insects were netted and classified. All specimens were of the order Heteroptera. Two Pentatomidae were netted near the Line Islands, and 4 Gerridae were taken within 1200 km of Christmas Island (Gressit et al., 1962).

NEKTON

INVERTEBRATE NEKTON

Nekton comprise the larger and faster free-swimming marine animals. Among invertebrate nekton are mainly included crustaceans, cephalopods, siphonophores, and other groups. Some of these animals, such as the euphausiids

and larger crustaceans at larval stages, may be classified as macrozooplankton if their size is small enough to make their swimming activities negligible except for diel vertical migrations within a particular locality. Studies of these smaller animals have been discussed above under "Zooplankton." Those cited in this section pertain to organisms no smaller than 1-10 cm and capable of classification at least as "micronekton."

The taxonomic composition and distribution of invertebrate micronekton were studied from night catches at 90 m and above, throughout the eastern tropical Pacific, including stations within the northeastern corner of DOMES (Blackburn, 1968). More than 93% of the samples consisted of several families of crustaceans and cephalopods: Galatheidae, Euphausiidae, Penaeidae, Squillidae, Portunidae, Sergestidae, Enoploteuthidae, Cranchiidae. Some of these groups were localized, but others were widely distributed according to specific eutrophic conditions. The role of nekton as a food source for fishes has been investigated in a study specific to DOMES (Blackburn, 1976).

Within DOMES, a giant specimen of Gnathophausia ingens (Dohrn, 1870) (Mysidacea) was collected in the deep waters below 2000 m in the vicinity of 8°N, 119°W, during the Scripps Eastropic expedition (Clarke, 1961). Despite its extraordinary size, one-and-a-half times larger than any previously recorded individual, the taxonomic classification appeared accurate. Gnathophausia are bathypelagic, and occur throughout the world ocean in tropical or subtropical regions. G. gigas and G. gracilis have subsequently been reported within the eastern portion of DOMES (Pequegnat, 1965). G. ingens generally ranges farther into the higher latitudes. G. gigas appears to have a greater bathymetric range than the other species; although it tends to occur at greater depths, it has also been collected above 1000 m. This species also was taken consistently at deeper levels during daytime hauls than at night, suggesting possible

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vertical migration. G. ingens is occasionally parasitized by the protozoan ellibiopsid flagellate, Amallocystis fasciatus (Pequegnat, 1965).

Several studies have dealt with nekton outside of but adjacent to DOMES. The distribution of the amphipod crustacean family, Phronimidae, was studied in tropical waters from 5°N to 20°S at 170°E (Repelin, 1972). Nine new species were reported in samples taken by the R/V Coriolis during its 1965-67 cruise. The greatest densities occurred in equatorial waters, with some decrease in the case of a convergence taking the place of the upwelling. Only 6 species appeared in these nutrient-rich waters of upwelling systems.

Studies of pelagic shrimps of the Natantia, Penaeidea and Caridea groups north of DOMES, from 22°N to 56°N, were made using samples taken during the John R. Manning Cruise 22, the Hugh M. Smith Cruise 27, and other expeditions. Forty-one species of pelagic shrimp, representing 13 genera, were observed, and their zoogeography discussed in relation to physicochemically defined water masses (Wasmer, 1972). Most of the species did not follow the boundaries of water masses, but were either localized within one, or overlapped these areas. These findings suggest that pelagic shrimp within DOMES may be similarly distributed, without regard to water mass boundaries within it. The pontoniid shrimps Palaemonella tenuipes and P. pottsi have been observed in DOMES (Bruce, 1970).

On the other hand, in certain squid species, distribution appears connected to some extent to water masses, as well as to patterns of zooplankton distribution (Wormuth, 1971). Squid in the Oegopsid family Ommastrephidae, inhabiting the Pacific Ocean from 40°N to 40°S, display two general distribution patterns: pelagic, and neritic around islands. Predator-prey relationships have been studied as part of a general survey.

Squid appear to be capable of underwater sound production. An investigation of this phenomenon, using a sound spectrograph, was made at 2°N, 150°W

during the 1958 cruise of the R/V Hugh M. Smith (Iversen et al., 1963). The mechanisms of squid sound production remain unknown.

The siphonophorid coelenterates form another major group of invertebrate nekton reported within DOMES as part of a general survey of their distribution throughout the world ocean (Alvariño, 1971). Data used in this study were compiled from 34 sources including the EQUAPAC Stranger in its August-September 1956 cruise of the equatorial central-western Pacific, from 175°W to Hawaii, sampling at depths of 0-700 m. The siphonophores collected and classified included 14 families and 3 orders, exhibiting tremendous morphological variety. Distributional patterns indicate that while the siphonophores, like the zooplanktonic chaetognaths, display faunal unity as between the Pacific and Indian Oceans, their species distribution does not correspond to water masses. Some siphonophores are global cosmopolites while others are restricted to specific types of localities, e.g., neritic or tropical habitats. A species list is presented, along with tables of geographical and bathymetric distribution and remarks on the unique features of certain species.

FISH

This literature survey does not include fish (See exclusions, p. 11 in the Introduction). For a review of existing information on fishes in the DOMES area, see Blackburn (1976).

NON-FISH VERTEBRATES

MARINE MAMMALS

The sparse literature treating non-fish vertebrates observed in DOMES is limited chiefly to marine mammals and birds.

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Whaling has been conducted in the Pacific for many years, and whales have been studied primarily by Norwegian, Japanese, and Soviet biologists. However, most whale migration patterns occur outside DOMES, either far to the north or to the east. The results of whale markings and recovery studied from 1954 through 1966 indicated that whales rarely range within DOMES (Ivashin and Rovnin, 1967). Three sperm whales and one sei whale were marked to the east of DOMES in 1965; 4 sperm whales and 3 sei whales were tagged in the same vicinity (90°W-110°W, 10°N-20°N) during 1966. None were recovered in or near DOMES, suggesting that the observed individuals were outside the typical migration patterns.

The small porpoise Stenella coeruleoalba has been sighted within DOMES, at 9°N, 178°W; 10°N, 124°W; and 11°N, 127°W; and it was sighted nearby on several occasions at 22°N, 108°W (Hubbs et al., 1973). These sightings, which took place between 1966 and 1972, indicate that Stenella coeruleoalba is one of the marine mammals occurring in DOMES, at least during winter and spring.

Distribution studies of Delphinus delphis Linnaeus (Evans, 1975) indicate that this porpoise, normally an inhabitant of northeastern Pacific or California coastal waters, does range as far west as 115°W, into DOMES.

A yearling male monk seal, Monachus schauinslandi, which breeds in the northwestern Hawaiian Islands and normally ranges only within the Hawaiian Archipelago, was sighted and identified on Johnston Island during 1968 (Schreiber and Kridler, 1969).

No other marine mammalian literature was found for the DOMES area, although other feral vertebrate forms occur on the islands, some of them (such as rats and cats) due to human contact. Clapp and Sibley (1971) described three species of lizard, Emoia nigra, Gehyra oceanica and Lepidodactylus lugubris, as well as the polynesian rat, Rattus exulans, on Caroline atoll.

BIRDS

Most of the birds observed in DOMES were studied within island habitats, although some sightings at sea have been reported.

King (1955) prepared an annotated list of birds observed on Christmas Island during 1953. He reported the existence of lizards, rats, and feral domestic cats, the latter major predators of ground-nesting birds. His observations included shearwaters, petrels, boobies, frigate birds, noddies, curlews, terns, turnstones, ducks, sanderlings, wandering tattlers, and gulls. He listed and described 22 species: Puffinus nativitatus, Pterodroma alba, Nesofregatta albigularis, Phaethon rubicanda melanorhynchos, Sula sula rubripes, S. dactylatra personata, S. leucogaster plotus, Fregata minor palmerstoni, Sterna fuscata oahuensis, Thalasseus bergii cristatus, Anous stolidus pileatus, Procelsterna cerulea cerulea, Anous minutus minutus, Gygis alba candida, Anas acuta tzitzihoa, Pluvialis dominica fulva, Numenius tahitiensis, Heteroscelus icanus, Arenaria interpres interpres, Crocethia alba, Larus delawarensis, and Conopoderas aequinoctialis aequinoctialis.

A similar list was compiled as the result of U.S. Fish and Wildlife Service observations of bird flocks in relation to fish schools from 1950 to 1961 (Waldron, 1964). This compilation lists birds sighted, in flocks and as scattered individuals, and correlates these with schools of skipjack and other commercial fish within three areas, including the Line Islands, over a series of three-month periods. These birds include terns, boobies, tropic birds, frigate birds, petrels, storm petrels, and shearwaters.

King (1974) subsequently edited a series of seven papers by various authors describing the pelagic distribution of sea birds in the central and eastern Pacific. These studies include descriptions of migratory patterns and seasonal distributions, as well as breeding and trophic patterns for the sooty

tern (Sterna fuscata), wedge-tailed shearwater (Puffinus pacificus), black-footed albatross (Diomedea nigripes), Laysan albatross (D. immutabilis), red-tailed tropicbird (Phaethon rubricanda), and 18 species of storm petrels (Hydrobatidae).

The bird life of Fanning Island was first noted by Captain Edmund Fanning (1924). Kirby (1925) described the indigenous avifauna. His observations were used as a baseline by Bakus (1967), who prepared an annotated list of current species in a comparative study. The bird population of the island has apparently undergone few changes.

Gordon (1970) reported observing the white-tailed tropicbird (Phaethon lepturus), the brown booby (Sula leucogaster) and red-footed booby (Sula sula), the lesser frigatebird (Fregata minor), the sooty tern (Sterna fuscata), the brown noddy (Anous stolidus), the Hawaiian noddy (A. minustus), and the fairy tern (Gygis alba) on Fanning Island during 1970. In addition to these seabirds, he reports four migratory species--the Pacific golden plover (Pluvialis dominica), the wandering tattler (Heteroscelus incanum), the ruddy turnstone (Arenaria interpres), and the bristle-thighed curlew (Numenius tahitiensis), as well as a snowy egret (Leucophoyx thula, believed to be accidental, and one land bird, the parakeet (Vinis kuhlii).

Very few studies exist which deal with the feeding patterns of avifauna within or adjacent to DOMES. Among these, the investigations of Ashmole and Ashmole (1967, 1968), conducted during 1963-64 on Christmas Island, are worthy of note. Food samples were taken from the various species of seabirds indigenous to Christmas Island to determine which would serve as the best indicators of seasonal data pertaining to ocean surface fauna (Ashmole and Ashmole, 1967). Although seasonal variations in tropical regions are not pronounced, information on breeding and growth patterns of fish, squid, and other food sources could be deduced from regurgitated samples. The birds most suitable

for research of this type appear to be terns, particularly Sterna fuscata and Gygis alba, noddies, Anous stolidus and A. tenuirostris, and the booby, Sula sula (Ashmole and Ashmole, 1968).

Research by Fisher (1973) concerning the intrusion of pollutants into the avian ecosystems indicates that on Midway Island, northwest of DOMES, albatrosses of the the species Diomedes nigripes and D. immutabilis have residues of DDT, DDE, PCBs, dieldrin, and mercury, within their visceral fat. Pollutant accumulation, from the principle food source, squid, and from scavenging, appears to exceed rates of dispersal, and may be expected to increase in these birds, because of their relatively long lifespans of 15-20 years. Furthermore, these species are high order carnivores; the level of pollutants at lower levels is not known, and may result in higher concentrations of contaminants in food sources.

Other avifaunal studies within DOMES deal with the natural history of individual species.

The failure of gulls to colonize tropical islands remains unexplained, although more than 50 sightings within the Line Islands (Sibley and McFarlane, 1968) indicate that Larus atricilla and L. pipixcan are frequent visitors, probably as the result of wind drifting.

A survey of petrels in the Central Pacific included pelagic sightings of Pterodroma neglects within DOMES (Gould and King, 1967). The lesser frigatebird, Frigata minor, has also been observed there (Sibley and Clapp, 1967). The breeding activities of the sooty tern, Sterna fuscata, on Palmyra, have also been studied (Mathewson, 1967).

There is evidence of avian colonization within DOMES; the Japanese white-eye (Zosterops japonica), a bird imported from Japan to the Hawaiian Islands in 1929 by private owners, appeared in 11 pelagic sightings from 1963 to 1965 (Ely, 1971). The fact that these birds appeared in flocks, 200 miles from

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land, suggested that the individuals observed in 1965 on Johnston's Island may have been natural arrivals. White-eyes occur in various Pacific islands, suggesting relative ease of dispersal. It is suggested that they may eventually inhabit the Line Islands.

BACTERIA

WATER COLUMN BACTERIA

Bacterial biosynthesis and metabolism are important processes in the transformation of organic matter in aquatic ecosystems. No information about marine bacteria from major studies exclusively in DOMES was found. However, some cruises have included stations within the DOMES area among other stations in the Pacific; thus, most bacterial research of this type is general in scope, those studies applicable to DOMES having been included here. A study pertaining to the Line Islands and nearby Hawaii was reported by Gundersen et al. (1972). During the 1971-72 NSF Cruises aboard the University of Hawaii R/V Teritu and Scripps R/V Melville, on the Honolulu to Papeete leg of the CATO II Expedition, samples were obtained at 20°N, 156°50'W, and at the 155°W meridian on the equator, at depths of 1200 m and 4750 m respectively. Experimental work included investigations on the ecology of nitrifying bacteria, and nitrate-reducing bacteria (Gundersen, 1974). Most observational data were deposited with the National Oceanographic Data Center and with the Hawaii Institute of Geophysics.

Formerly, it was believed that few microorganisms inhabited the deep sea, at 3800 m or deeper. Zobell (1968) pointed out that little is known about bacterial activity in extensive areas of the deep sea. In those regions which have received some attention, the bacterial populations appear to be characterized by great variety in type and variability in abundance.

Kriss et al. (1960) established that in the open ocean there is no simple relationship between depth and occurrence of heterotrophic bacteria in the water column. Samples taken from the 1957-58 Vityaz cruise, passing through DOMES, indicated that vertical distribution is more closely related to the occurrence of labile organic matter, the nutrient source for marine bacteria. More bacteria occur in the tropics, assimilating the easily accessible organic matter there. These heterotrophs may serve as indicators of water types.

Research conducted aboard the R/V Academician Korolyov, R/V Professor Vise, and R/V Academician Kurtchatov on cruises throughout the world ocean included extensive samplings of the vertical and geographical distribution of bacterial densities at several oceanic locations, including 47 stations in a region east of DOMES. Observations suggest that the distribution of bacteria in the world ocean at varying depths is quite irregular. Autochthonous and allochthonous organic materials play an important role in supporting bacterial density (Kriss et al., 1971).

Life processes have been found to occur at extremely low rates at great depths, as indicated by in situ incubation experiments conducted at 1800 m in the Atlantic (Jannasch and Wirsen, 1973). These findings are similar to those of an earlier study also in the Atlantic at 1540 m, which demonstrated rates of microbial degradation to be 10-100 times slower in the deep sea than in controls under comparable temperatures (Jannasch et al., 1971). Such slow rates are probably characteristic of bacteria at similar depths throughout the world ocean because of low temperature and sparse population.

During the 34th Vityaz expedition, Sorokin (1970a) analyzed the bacterial population, biomass, production, and the biochemical oxygen demand (BOD) at stations throughout the central Pacific, including DOMES, in various types

of ocean floor ranging from coral atoll lagoon sand to deep-sea red clay. His study included assessment of the number of saprophytic bacteria, total number and biomass of the bacteria, measurement of the relative activity of heterotrophic bacterial populations, determination of the assimilation of CO_2 by the microorganisms, and calculation of bacterial production as well as determination of the comparative biochemical oxygen demand by bacteria in sediments.

The resulting patterns of distribution of the bacterial populations and production are correlated with the general biological and geological zonalities of the ocean, specifically with the distribution of marine primary productivity and benthos. Bacterial processes and production were found to be 100 times lower in pelagic pelitic sediments than in some other areas, and there was very little reduction of compounds in these locations.

This research continued during the 43rd and 44th Vityaz cruises. Microorganisms were found to be exceedingly sparse, and their production insignificant at those locations in which iron-manganese concretions occur. Activity and production peaked at the sea surface and in the oxygen minimum zone from 300-500 m or from 400-600 m. These findings, along with P/B coefficients and tentative rates of oxygen utilization, were graphed and tabulated (Sorokin, 1970b, 1970c, 1971a, 1971b).

Kriss and Mitskevich (1971) plotted the vertical distribution of bacterial population densities at stations from 40°N to 32°S and 71°W to 90°W , near DOMES, from depths of 0-5000 m.

In a more comprehensive series of investigations, the quantitative vertical and geographical distributions of heterotrophic bacteria were studied aboard the R/V Academician Korolyov, to determine whether the heterotrophic bacterial biomass decreases indirectly, and at a regular rate, with distance from sources supplying the Pacific waters with allochthonous organic matter (Kriss and Stupakova, 1972; Kriss et al., 1972). The stations included two

in DOMES at 16°N, 135°W, and 9°N, 135°W. Density was found to decrease with distance from the western to the central Pacific, with layers of increased and decreased bacterial content alternating vertically. Density and number at various depths were graphed and tabulated for each station, including the one in DOMES, and a model of the hydrological structure of the water masses was constructed from the microbiological data.

In a classic study, Waksman and Renn (1936) demonstrated that under laboratory conditions, about 50% of the total organic matter in sea water undergoes conversion by heterotrophic microorganisms, 60% of which is oxidized to form "water humus" while 40% is consumed by the formation of bacterial cellular substances.

Continuing this line of investigation, Mel'nikov (1973), during the 48th Vityaz cruise, studied the degradation of organic matter by heterotrophic microorganisms in three Pacific water masses at four stations, one of which lies at 0°15'N, 179°36'W, near the southwestern corner of DOMES. In the equatorial waters, the process of bacterial degradation of organic matter ended at the depth of 300 m. The biochemical oxygen demand (BOD) method was used to determine quantitative aspects of the trophic link between organic matter in sea water and heterotrophic microorganisms.

Highest productivity occurs in the vicinity of coral reefs, atolls, and island systems, for reasons which are not yet well understood. C^{14} -labelled bacteria in Fanning Island Lagoon exhibited productivity and biomass tens and hundreds of times greater than those of pelagic regions (Sorokin, 1973).

The few extant studies of the metabolic processes of marine bacteria include that of Seki (1968) aboard the R/V Ryofu Maru. Seki's samples, taken from the western North Pacific, exhibited characteristics in the laboratory believed to be typical of heterotrophic bacteria in all the near-surface waters. They grew best at 30°C and in a 30‰ salinity, with polypeptone con-

centrations of 3%-5%. Glucose assimilation in sea water was carried out primarily by organisms smaller than 5 microns in diameter.

Hamilton and Preslan (1970) examined substrate uptake by microbial populations at several EASTROPAC stations in the vicinity of DOMES. Ten C^{14} -labelled substrates were used as indicators of kinetic activity. Some, but not all, results conformed to Michaelis-Menten enzyme kinetics, and these variations could not be explained or correlated with specific in situ variations in descriptive parameters. A strong correlation was observed between the uptake of proline and the concentration of viable bacteria as determined by plate counts. Deviations of this sort have been previously explained as being due to the existence of competing heterotrophic communities (Vaccaro and Jannesch, 1967).

Packard et al. (1971) measured electron transport system (ETS) activity and oxygen-utilization rates of microorganisms in the Peru Current. Samples were taken during Cruises 32, 35, and 36 of the R/V Thomas G. Thompson, at 20 stations including some near DOMES: $30^{\circ}N$, $123^{\circ}W$; $35^{\circ}N$, $121^{\circ}W$; and $33^{\circ}N$, $119^{\circ}W$. Vertical profiles from the surface to 5000 m suggest a rapid decrease in oxygen utilization from $300 \mu l O_2 \text{ liter}^{-1} \text{ yr}^{-1}$ in the euphotic zone to $3 \mu l O_2 \text{ liter}^{-1} \text{ yr}^{-1}$ at 500 m and $0.5 \mu l O_2 \text{ liter}^{-1} \text{ yr}^{-1}$ at 5000 m.

Devol (1975) investigated the rates and regulation of biological oxidations in sea water, using enzymatic, polarographic and incubation techniques. Both oxic and anoxic systems were studied, with special attention focused upon the transitional zone. Reduction of nitrate to nitrite was also examined. Vertical profiles of ETS activity exhibited a distinct maximum at the transitional zone, believed to be the result of intracellular biochemical changes. The Michaelis-Menton oxidation uptake constant, K_t , was about 2 microgram-at. oxygen/liter within most of the eastern tropical north Pacific, but slightly

lower within the oxygen minimum zone, indicating that bacteria commence use of nitrate in respiration at lower oxygen concentrations in these regions.

BENTHIC BACTERIA

Marine bacteria are now generally believed to play a role in the formation or enhancement of manganese nodules. The most significant earlier studies on this subject were made by Ehrlich (1963, 1966, 1972), Trimble and Ehrlich (1970), and Ehrlich et al. (1972), using microorganisms from the Atlantic and Pacific Oceans. Their findings are applicable to DOMES. Microorganisms found on the surface and throughout the nodule structure consist of Mn(II) oxidizers and MnO₂ reducers. The Mn(II) oxidizers promote manganese accretion to nodules by enzymatically catalyzing the oxidation of Mn(II) pre-adsorbed to Mn(IV). MnO₂-reducing bacteria enzymatically convert Mn(IV) to Mn(II) while oxidizing reduced carbon, a process accompanied by solubilization of trace Cu, Co and Ni, but not Fe in the nodules.

Sorokin (1972) extended this research to the Pacific, using data obtained during the 43rd Vityaz cruise. The marine microorganisms Metallogenium, Pedomicrobium, and Gallionella were found to be manganese-oxidizers. However, the findings of Greenslate (1974) indicate that microorganisms such as the benthic Foraminifera, Saccorhiza, are also implicated in the accretion of the nodules, by shelter-building activities.

BENTHOS

The DOMES area benthic habitats and their biota include a wide range of conditions and species, including organisms from intertidal and subtidal shallow-water systems of islands, guyots-seamounts, and the deep-sea bottom. Coral reef ecosystems and island systems occur in DOMES; however, the abyssal

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plains are the most common habitat type. Studies of benthic organisms cited below refer to macrofauna, unless otherwise specified.

DEEP-SEA MACROFAUNA

The definitive compendium on deep-sea benthos of the Pacific is that edited by Zenkevich (1970). This volume gives a history of benthic investigations and articles on the type and distribution of deep-sea bottom fauna by Belyayev, Filatova, Pasternak, Vinogradova and others during 31 cruises by the R/V Vityaz in the Pacific, including numerous stations in DOMES.

Topics include the geographic, bathymetric and quantitative distributions of fauna and the taxonomic composition of 28 groups in 11 Phyla: (1) Protozoa (Foraminifera), (2) Spongia, (3) Coelenterata, (4) Mollusca (Monoplacophora, Gastropoda, Bivalvia, Scaphopoda), (5) Annelida (Echiuroidea, Polychaeta, Sipunculoidea), (6) Pogonophora, (7) Arthropoda (Pycnogonida, Cirripedia, Mysidacea, Amphipoda, Isopoda, Tanaidacea, Cumacea, Decapoda), (8) Echinodermata (Asteroidea, Crinoidea, Echinoidea, Holothuroidea, Ophiuroidea), (9) Bryozoa, (10) Brachiopoda, (11) Chordata (Ascidacea).

The stenobathic fauna exhibit distributional patterns generally delineated by macro-relief boundaries of the ocean floor. Species of deep-sea benthic macroinvertebrates with a wide geographical range tend also to have an extensive vertical range, permitting them to transcend these boundaries. Almost all cosmopolitan species are eurybathic. Endemism tends to increase with depth of habitat; thus, stenobathic species occur mainly in restricted locations (Vinogradova, 1959).

The macro-benthic biomass drops in southern parts of the northern Pacific, from 40°N toward the equator, with minima under the central gyre of north

Pacific circulation. Food supply from overlying waters to the bottom thus appears to be a principal factor influencing quantitative distribution and abundance of these organisms (Filatova and Levenstein, 1961; Levenstein, 1970).

Previous work by Vinogradova (1960, 1962) indicated differences in the bathymetric distribution of some of the taxa of invertebrates living at or below 2000 m. These include Spongia, Coelenterata, Crustacea (specifically Cirripedia, Isopoda, and Decapoda), Pantopoda, Echinodermata (Crinoidea, Asteroidea, Echinoidea, Holothuroidea) and Pogonophora, a total of 1,144 species, only some of which occur in the DOMES area. From 2000 m to 6000 m the number of species decreases rapidly, with maximum depth of occurrence varying between taxa. For most, in abundance and rate of species replacement, maxima are at 3000-3500 m and 4000-4500 m. Cirripedia, Decapoda, Crinoidea, and Echinoidea indicated no depth maxima; however, changes of taxonomic composition occurred at 3000 m and at 4000-4500 m. Thus, the abyssal region may be divided into two faunal zones, an upper and a lower. The causes of zonal distribution are not well understood, but they may include differences in feeding behavior, detritus feeders being capable of existence at greater depths.

A general study examining average macrofaunal biomass, its decrease with depth and its relationship to surface productivity, indicates that this latter factor, while secondary to the effects of depth, is significant in determining the biomass of any region (Rowe, 1971).

Sokolova (1972) used data obtained on the Vityaz cruises to examine the trophic structure of the benthos. Benthic macrofauna were classified as deposit feeders, suspension-feeders, and carnivores. Information on species distribution was correlated with rates and nature of sedimentation, content of organic carbon in sediment, degree of transformation of organic matter, redox potential, oxygen consumption, and the state of heterotrophic microflora organisms in sediments. Findings suggest that regions of high biomass are

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characterized by high surface-layer productivity and large quantities of digestible organic matter sufficient for deposit feeders to predominate in these areas; in oligotrophic regions of the open ocean with low sedimentation rates and scarce quantities of deposited organic material, suspension feeders comprise a major trophic type. Subsequent investigations (Hessler and Jumars, 1974) indicate that deposit feeders dominate oligotrophic areas as well as regions of high biomass.

The work by Hessler and Jumars (1974), who used box core samples in a region north of but relevant to DOMES (because of the relatively uniform nature of the deep-sea environment), investigated the abyssal community of an oligotrophic manganese nodule-red clay locale. The trophic characteristics of exemplars of certain groups are described: deposit feeders, suspension feeders, and scavengers. Their findings cast doubt on the importance of suspension feeders.

The deep-sea fauna throughout the world ocean displays uniformity at the higher taxonomic levels, and even genera tend to be cosmopolitan. Certain general patterns exist in all locations: standing crop decreases seaward and with increasing depth, with observed shifts in the numbers and proportions of macrofaunal taxa (e.g., polychaetes, amphipods and bivalves decrease; there is an increase in the importance of tanaids and isopods). The general ubiquity of deep-sea fauna is related to basic similarities of temperature, light, conditions of sedimentation, currents, pressure, and temporal stability (Hessler, 1974). Rowe (1974) discusses the effect of the burrowing of the infauna on sedimentary properties.

MEIOBENTHOS IN DOMES

Measurements of the wet weight of the meiobenthic biomass, obtained using #140 gauze, were made during the 43rd cruise of the R/V Vityaz at numerous stations, including more than a dozen in DOMES. Findings, ranging from

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0.016 g/m² to 0.47 g/m², were used to characterize oligotrophic, eutrophic, and intermediate regions: eutrophic regions have 10 to 30 times more meiobenthic organisms than do other areas (Sokolova, 1970).

Saidova (1970) has established six major zoogeographical provinces and 22 subprovinces, inhabited by 1550 species of benthic Foraminifera. Three of these major provinces are represented in DOMES: (1) the Central Province, in the western portion of DOMES, includes small sectors of the north-central and marginal subprovinces, containing 26 and 66 species, respectively; (2) the Southeastern Province, western subprovince, containing 225 species, comprises most of DOMES; and (3) a small area along the northeastern border of DOMES lies in the American Province, specifically the central-American subprovince, containing 126 species, and a small part of the California subprovince with 191 species in colder water. Endemic species occur in each of these subprovinces. Investigations of standing stock within the eastern Pacific oxygen minimum indicate that oxygen is not a limiting ecological factor for benthic Foraminifera (Phleger and Soutar, 1973).

DEEP-SEA MACROBENTHOS NEARBY DOMES

Studies of a biochemical nature include investigations of the distribution of elements in the tissues of benthic organisms (Riley and Segar, 1970), which may be valuable as baseline indicators of environmental changes and their impact upon the physiology of deep-sea fauna. The concentration of iron and other trace elements in benthic Foraminifera appear not to be influential in the forming of manganese nodules (Dudley and Margolis, 1974), as was once suggested (Greenslate, 1974).

Some other benthic groups have been investigated in a variety of unrelated studies. Eldredge (1965) classified 23 species of ascidians, the

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Didemnidae, in the central Pacific, adjacent to DOMES, and subsequently extended his research into the DOMES region (Eldredge, 1966).

The study of Fauchald (1972) of benthic polychaetous annelids and their taxonomic distribution, while limited to deep waters off western Mexico and the eastern Pacific nearby, included 49 species in 14 families, some of which are probably also found in the eastern portion of DOMES.

Scavenging abyssal amphipods (Schulenberger and Hessler, 1974) have been reported under the oligotrophic waters of the central North Pacific Gyre northwest of DOMES, and probably also inhabit DOMES. Although there are no comparable studies of DOMES itself, deep-water isopods were collected and classified during the 1949 and 1953-58 cruises of the Vityaz, from 1000-8430 m, at 170°W, from 57°-24°N, just north of DOMES (Birstein, 1963). Some of these species may be expected to occur in DOMES.

INTERMEDIATE DEPTHS: GUYOTS, SEAMOUNTS

During the 1968 Styx-Leg 7 (Scripps Expedition) aboard the R/V Alexander Agassiz, deep-water molluscs were trawled from Horizon, Hess, Allison, and Agassiz guyots in DOMES (Rehder and Ladd, 1973). Seven species--two trochids, three turrids, one scaphopod, and one bullid were identified from deep waters. The bullid, Bulla argoblysis, is a cosmopolite; one turrid, Pleurotomella allisoni, is normally found in the Galapagos Islands. The other five species were closely related to Indo-Pacific forms.

A mollusc of the class Monoplacophora, a Cambro-Devonian "living fossil," was found on the slope of the Marcus-Nekker seamount, at 20°41'7"N, 170°52'9"W, during the 43rd cruise of the R/V Vityaz (Filatova et al., 1968). Other epifauna, found in the same location, consisted of glass sponges, diverse Coelenterates (Alcyonaria, Zoantheria), Polychaetes (Serpulidae, Sabellidae), Cirripedia, Bryozoa, and Ophiuroidea.

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The thoracic Cirripedia occupy guyots in the mid-Pacific submarine mountain ranges. Currents responsible for erosion of guyot summits may be an explanation of the distributional patterns of these barnacles on the guyots (Rao and Newman, 1972). These barnacle species do not generally attach themselves to manganese-coated surfaces.

It is generally accepted that biological processes of benthic organisms play some role in the extraction of rare elements, including Mn, from seawater and subsequent concretions of these elements (Graham, 1959; Graham and Cooper, 1959; Greenslate et al., 1973; Greenslate, 1974, 1975). Benthic bacteria, in particular, are associated with manganese nodules, as was discussed previously.

SHALLOW WATER

Shallow-water bottom invertebrates have generally been studied as fauna belonging to specific island or reef systems (Hadfield, 1976), although few of these animals are endemic; many are common to similar habitats at all islands or reefs within DOMES, or nearby. Specific distribution patterns such as among individual island or reef systems within DOMES have seldom been investigated.

Antonius (1971) reported the distribution of Acathaster planci (Echinodermata) throughout the tropical Pacific, in a study believed applicable to all locations in this general area, including DOMES. Similar studies have been made by Glynn (1974) and Dana (1975). However, Emerson (1967) addressed his research to the question of why Indo-Pacific elements comprise such a relatively small portion of marine benthic fauna in the eastern tropical Pacific. Such species occur in the Line Islands, and at Clipperton Island, but comprise only 10% of the molluscan fauna at Clarion Island, in the Revilla Gigedos. Clearly, these latter islands in the eastern portion of DOMES lie to the east of a significant faunal barrier, characterized on its eastern side by

an impoverishment of the development of coral reefs, a common habitat feature of many Indo-Pacific benthic invertebrate groups.

Some animals which are not dependent upon reefs have bridged this faunal barrier; the sand crab Hippa pacifica inhabits not only the Galapagos and Socorro Islands within the coastal American zone, but Clipperton and the Hawaiian Islands as well (Efford, 1972), and may possibly occur at other islands in DOMES.

Clipperton Island, with the only coral atoll in the eastern Pacific, thus contains both Indo-Pacific and Panamanian species, particularly of molluscs, as reported in various faunal studies (Hertlein, 1957; Hertlein and Allison, 1966, 1968).

The study of taxonomic distributions of alpheid shrimp made by Banner and Banner (1964) includes material from the Line Islands, within DOMES, as well as the Phoenix Archipelago, and includes Johnston Island, with environmental data from the variety of habitats common to all locations.

These data were supplemented with additional collections to include other crustaceans in the Line Islands, reported by habitat type (Guinther and Banner, 1970). Brock (1973) reported the occurrence of another crustacean, the lobster Panulirus marginatus, on Johnston Island, as part of a distribution survey extending over a wide area. The genera of marine benthic algae found on Johnston Island may link this atoll to other islands as regards habitat and biotope type (Buggeln and Tsuda, 1969).

The polychaetes of Palmyra have been described by Hartman-Schroeder (1964). Subsequently, Young (1967) identified 28 species of nudibranchs, of the opisthobranchiate gastropod group, on Palmyra Island, Johnston Island (just inside DOMES), and Eniwetok Atoll in the Marshall Islands. Feeding habits included predation of gastropod egg masses, sponges, and polychaetes. The prosobranch gastropod Coralliophila violacea, which feeds upon its stony coral

host, has been reported throughout tropical waters, including Clipperton Island (Robertson, 1970). The Terebridae, one of the most abundant molluscan components of tropical sandy beaches, include a group lacking radular teeth; they make use of an accessory feeding organ which appears to function primarily by ingesting tentacles of cirratulid polychaetes (Miller, 1970).

In a study of 8 habitat zones in the Hawaiian Islands and Johnston Atoll, Bailey-Brock (1976) described 47 species of tube-building polychaetes belonging to the following families: Spionidae, Chaetopteridae, Sabellariidae, Terebellidae, Sabellidae, and Serpulidae.

Of all the islands in DOMES, Fanning Island has been studied most extensively. Many investigations took place during the Fanning Island Expedition. Most studies of the atoll deal with molluscs, reef corals, and animals found in the sediments, and these are summarized in Chave (1970) and Chave and Kay (1974), the two most important sources of information about Fanning Island.

At Fanning Island, Stasek (1965) examined the behavioral adaptation of the giant clam Tridacna maxima to the presence of grazing fishes, using field and laboratory observations. A variety of other molluscs inhabit supratidal, upper tidal, littoral, eulittoral, seaward, and lagoon shores in distributional patterns which are species-specific (Kay, 1971). Three major habitats consist of the lagoon reef flat, patch reefs, and the lagoon floor. Lagoon molluscs are distinguished from seaward reef molluscs by species composition, modes of life, and feeding habits. Most lagoon macrofauna are epifaunal herbivores; most seaward reef macrofauna are carnivores and faunal grazers. The standing crop of seaward reef micromolluscs is smaller, with a higher species diversity index, than that of lagoon species (Kay and Switzer, 1974).

Several studies have been made of the development of hermatypic corals on Fanning Island. Forty-two species have been found within the lagoon, 28 of which inhabit turbid water. These include the following genera: Acropora,

Tubastrea, Fungia, Hydnophora, Merulina, Montipora, Lobophyllia, Pocillopora, Porites, and Stylophora, and also tentative identifications of Astreopora, Favia, and Platygyra (Maragos et al., 1970). Growth of Pocillopora lingulata was calculated over a two-year period, by weight measurement (Roy and Smith, 1970). Lack of light and extensive rates of sedimentation were found to be factors which limit coral reef development, particularly in turbid waters, where the introduction of fine-grained sediment stunts and kills the reef (Roy and Smith, 1971). Additional studies of hermatypic corals were made by Stehli and Wells (1971).

Other corals found on Fanning Island bring the total number of species to 70, belonging to 32 genera and subgenera, of which the greatest diversity occurs on leeward ocean reefs (Maragos, 1974a). This diversity, however, is less than that reported for island groups in the western Pacific. Geographical isolation may account for this reduced diversity. Seaward reef communities could be divided into three assemblages, related to depth, according to data obtained by SCUBA and quadrant transect techniques (Maragos, 1974b). At a depth of 8-15 m, the reef was characterized by moderately high diversity, and smaller average colony size; at 20-24 m, colony size was larger, but dominated by fewer species groups; the deepest assemblage, 30-35 m, exhibited smallest colony size but greatest species diversity. Wave action appears to disrupt otherwise optimal conditions for reef development.

Sedimentation processes have been frequently mentioned in the above studies as factors influencing the ecosystem of Fanning Island. Not only coral reef development, but sponges and ascidians appear to be adversely affected by sediment deposition, which buries organisms, or clogs canals and chambers (Bakus, 1968). This adverse effect tends to limit the numbers of sponges and ascidians found in regions of high sedimentation rates, such as in English Harbor. Sedimentation, particularly silication of bioclastic

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particles measuring from 75 to 225 microns in diameter, was presumed to originate from outside the atoll, and to depend primarily upon currents and water movements. However, recent studies indicate that the boring sponge, Cliona, penetrating carbonate substrates, produces particles ranging from 15 to 100 microns in size; these account for 30% of the tidal sediment of the Lagoon (Fütterer, 1974).

DeWreede and Doty (1970) observed major algal flora on the atoll, listing 14 Chlorophyta, 4 Phaeophyta, 9 Rhodophyta, and 3 Cyanophyta. This study compares the Fanning Island algal flora with that of the other Line Islands, and provides a key for identification.

In a similar but earlier investigation on Palmyra Island, Dawson et al. (1955) reviewed and tabulated all known field collections from the atoll, including 11 species of Cyanophyta, 15 Chlorophyta, 2 Phaeophyta, and 11 Rhodophyta. Additional examination of the alimentary tracts of reef fishes resulted in the identification of 63 species of sessile algae, 5 dinoflagellates, 86 diatoms, and one silicoflagellate.

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